ESSAYS ON AGRICULTURAL MARKETS IN DEVELOPING COUNTRIES: SMALLHOLDER MARKET PARTICIPATION, THE ENABLING ENVIRONMENT FOR FERTILIZER IMPORTS, AND STAPLE FOOD PRODUCT PRICE UNCERTAINTY

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ABSTRACT

ESSAYS ON AGRICULTURAL MARKETS IN DEVELOPING COUNTRIES: SMALLHOLDER MARKET PARTICIPATION, THE ENABLING ENVIRONMENT FOR FERTILIZER IMPORTS, AND STAPLE FOOD PRODUCT PRICE UNCERTAINTY

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Robust and vibrant agricultural markets are an important component of inclusive agriculture-led economic development. Governments of developing countries play an important role in fostering an enabling environment for agricultural markets to thrive and in addressing shortcomings arising due to incomplete agricultural markets. However, excessive government involvement can also lead to inefficiencies and can further obstruct the development of agricultural markets. This dissertation focuses on various agricultural market outcomes and evaluates them in light of government interventions that potentially have a direct or indirect effect on them.

The first essay investigates whether and how liquidity constraints during the production period affect smallholders' market participation and choice of marketing channel in the context of the Zambian maize market. During the period of the study, the country's parastatal marketing board – the Food Reserve Agency (FRA) – operated alongside private buyers and purchased large volumes of maize at a pan-territorial price that exceeded average market prices. Results indicate that liquidity-constrained maize-growing smallholders produced less maize output, were less likely to sell maize, and were less likely to sell to the FRA, as compared to those that did not face liquidity constraints. These results imply that benefits of market policies like those of the FRA are likely to be disproportionately captured by relatively wealthier and less resource constrained farmers.

The second essay focusses on the effects of various regulations imposed on international trade and the domestic fertilizer market on fertilizer imports - an important component of domestic fertilizer supply in most developing countries. The results indicate that increased time and/or costs needed to comply with border regulations (such as clearing customs and inspections) are associated with a decline in the volume of fertilizer imported. However, fertilizer market-specific regulations are not found to be statistically significantly associated with fertilizer imports. Further investigation reveals that the border regulation-related findings hold mainly for high and middle-income countries, plausibly due to poor enforcement of formal laws and the greater importance of informal rules in the markets of low-income countries.

The third essay explores whether price uncertainty (a form of price volatility) affects the price levels of maize products in urban Zambia, in light of the highly discretionary and ad-hoc government interventions in the country's maize markets. Excessive price volatility of staple food products has adverse effects on food and nutritional security of vulnerable populations and can potentially disrupt the development of resilient food markets. I conduct a Vector Autoregressive-Generalized Autoregressive Conditional Heteroscedastic (1,1)-in-mean (VAR-GARCH(1,1)-in-mean) analysis of monthly price data for four maize products: wholesale maize grain, retail maize grain, and two types of maize flour – breakfast meal (highly refined) and roller meal (less refined). I find some weak evidence that an increase in uncertainty in wholesale maize grain prices is associated with a small increase in own prices, although this result does not hold across all specifications. Price uncertainty of other products is not found to be associated with changes in prices of own or other products. The application of VAR-GARCH(1,1)-in-mean to model prices of food products across a value chain is a methodological improvement over existing studies in this area in a developing country context.

Dedicated to *Daadi*, my late grandmother -- a lifelong practicing smallholder farmer -- whose hard work, resilience, and enduring compassion for all living beings continues to inspire me.

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KEY TO ABBREVIATIONS

AMIC	Agricultural Marketing Information Centre
EBA	Enabling Business of Agriculture
FRA	Food Reserve Agency
TAB	Trading Across Borders
CSO	Central Statistical Office
CRE	Correlated Random Effects
MNL	Multinomial Logit
POLS	Pooled Ordinary Least Squares
LC	Liquidity Constrained
UC	Liquidity Unconstrained
CAPM	Conditional Asset Price Mechanism
VAR	Vector Autoregression
GARCH	Generalized Auto-Regressive Conditional Heteroscedastic
SSA	Sub-Saharan Africa
RALS	Rural Agricultural Livelihoods Survey
ACF	Autocorrelation Function
PACF	Partial Autocorrelation Function

INTRODUCTION

Governments play an important role in creating and fostering an enabling environment or the ‘rules of the game’ within which robust and vibrant agricultural markets can thrive (Christy et al., 2009; Diaz-Bonilla et al., 2014). When some agricultural markets are incomplete, such as in case of developing countries, governments may adopt wider roles in facilitating agricultural markets, such as to reduce transaction costs, ensure the quality of products, and improve food security among vulnerable populations (Innes and Rausser, 1989; Innes, 1990; Innes, 2002; Larson and Gurara, 2013). However, excessive government involvement may also create inefficiencies and can further obstruct the development of agricultural markets (Poulton, Kydd, and Dorward, 2006; Holden, 2019). In this dissertation, I study various agricultural market outcomes, such as participation of smallholders in agricultural markets, their choice marketing channel, the quantity of fertilizers imported by a country, and the prices of staple food products, and evaluate them in light of various government interventions that potentially have direct or indirect effects on these market outcomes. In this context, the first essay addresses the Zambian government’s maize grain purchase program that was implemented through the parastatal maize marketing board and strategic grain reserve, the Food Reserve Agency (FRA). The second essay focusses on government regulations on international trade and the domestic fertilizer market that are likely to impact fertilizer imports - a very important component of domestic fertilizer supply in most developing countries. The third essay studies the prices of various maize products in Zambia against the backdrop of high maize price volatility experienced by the country, for which discretionary government intervention in maize markets is often held partially responsible.

In the first essay (Chapter 1), I investigate whether and how liquidity constraints in the production period, which can limit smallholders' investment in productivity-enhancing agricultural inputs, affect smallholders' market participation and choice of marketing channel. To increase smallholders' market participation, developing country governments sometimes intervene in domestic grain markets through large scale grain purchase and price support programs. However, the benefits of such programs may not reach farmers who face production constraints, such as liquidity constraints, that inhibit their ability to produce a marketable surplus. I explore this issue in the context of the Zambian maize market. During the period of the study, the country's parastatal maize marketing board – the FRA – operated alongside private buyers and purchased large volumes of maize at a pan-territorial price that exceeded average market prices. I find that liquidity-constrained maize-growing smallholders produced less maize output, were less likely to sell maize, and were less likely to sell to the FRA, as compared to those that did not face liquidity constraints. A key takeaway is that market policies like those of the FRA are less likely to benefit smallholders who do not possess the resources to increase production. Rather, the benefits of such policies are likely to be disproportionately captured by relatively wealthier farmers.

In the second essay (Chapter 2), I study the effect of government regulations on fertilizer imports using a cross-country panel analysis. I test the hypothesis that more stringent or onerous regulations on international trade (measured as the time and costs of border and documentary compliance) and on the domestic fertilizer market (measured through indicators of rules about fertilizer import permits and registration of new fertilizer products) are correlated with lower fertilizer imports. The results indicate that increased time and/or costs needed to comply with border regulations (such as clearing customs and inspections) are associated with a decline in the volume of fertilizer imported. It is difficult to disentangle the effects of the time and costs of compliance with border regulations on fertilizer imports due to the moderately strong correlation between the two variables. Border compliance is likely to be consequential to fertilizer imports due to the bulky nature of fertilizers and the need for proper handling at borders and ports to avoid losses of quantity and quality of the product. Fertilizer market specific regulations are not found to be statistically significantly associated with fertilizer imports. Further investigation reveals that the results are robust for high and middle-income countries but are not statistically significant for low-income countries. The lack of significance in the case of fertilizer-specific regulations may be due to low statistical power, confounding factors such as government-sponsored fertilizer programs, and/or poor enforcement of formal laws in low income countries.

In the third essay (Chapter 3), I focus on excessive price volatility of staple food products, which has been found to have adverse effects on food and nutritional security of vulnerable populations and to potentially disrupt the development of resilient food markets. Specifically, I study whether price uncertainty (a form of price volatility) affects the price levels of maize products in urban Zambia. Using the Conditional Asset Pricing Model (CAPM) as the theoretical motivation, I argue that risk averse maize market players (e.g., traders and processors) will demand higher margins for investing in maize products if their prices are very uncertain. This translates into the testable hypotheses that high price uncertainty in wholesale maize grain prices is associated with higher prices for retail maize products (retail maize grain, roller meal, and breakfast meal); on the other hand, high price uncertainty in the retail maize product prices is expected to be associated with lower wholesale prices for maize grain. The expected effect of own price uncertainty on own price levels is ambiguous. Using a Vector Autoregressive-Generalized Autoregressive Conditional Heteroscedastic (1,1)-in-mean (VAR-GARCH(1,1)-in-mean) approach and monthly data on maize product prices that have been converted to annual price returns, I find some weak evidence that price uncertainty of wholesale maize grain is positively associated with its own price returns ($p<0.1$); however, this result is not robust across all model specifications. Price uncertainty in the other products is not found to be statistically significantly associated with changes in price returns of own or other products. The application of a VAR-GARCH(1,1)-in-mean approach to model prices of food products across a value chain is a methodological improvement over existing studies in this area in a developing country context. It helps in capturing information about prices across a value chain that could not be captured using univariate models that have been more commonly used in past studies.

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CHAPTER 1

SMALLHOLDER MARKET PARTICIPATION AND CHOICE OF MARKETING CHANNEL IN THE PRESENCE OF LIQUIDITY CONSTRAINTS: EVIDENCE FROM ZAMBIAN MAIZE MARKETS

1.1 Introduction

Uncompetitive markets and poor market access are identified as important reasons for limited market participation in agricultural markets by smallholder farmers in developing countries (Goetz 1992; Key et al. 2000; Heltberg and Tarp 2002). This perspective, while well supported by evidence, often overlooks an additional limitation to smallholder participation in agricultural markets: constraints that smallholders face in producing a marketable surplus. This is especially relevant for staple food grains, the selling of which is often conditional on the production of a surplus beyond the household’s consumption needs. A major constraint faced by smallholders in developing countries is the inability to invest adequately in crop productivity-enhancing inputs due to lack of liquidity during the production period (Duflo et al. 2011; Kusunose, Mason-Wardell, and Tembo 2020). This is known to reduce households’ agricultural production (Feder et al. 1990; Foltz 2004; Winter-Nelson and Temu 2005) and consumption (Carter and Lybbert 2012), but its effects on smallholders’ ability to participate in and benefit from lucrative agricultural output markets are not well understood. Further, the link between liquidity constraints and agricultural output market participation is not straightforward. Lower agricultural production can either lead to reduced food consumption, reduced sales, or a combination of both. If the sale of agricultural output provides an opportunity to meet immediate cash needs and smoothen consumption (Stephens and Barrett 2011) or diversify food consumption (Ntakyo and van den Berg 2019; Mulenga, Ngoma, and Nkonde 2021), then the effect of reduced agricultural production due to liquidity constraints on sale of agricultural output is ambiguous and warrants a thorough empirical investigation. In this article, we use nationally representative panel data from maize-growing smallholders in Zambia to empirically test the effect of liquidity constraints during the production period on maize marketing behavior. We find that liquidity constrained households are indeed less likely to sell maize, as compared to liquidity unconstrained households. Moreover, when liquidity constrained households do sell, they are less likely to take advantage of a marketing channel that offers a higher price but involves higher fixed costs to be accessed.

Increased participation of smallholders in agricultural output markets can potentially shift farmers from high-risk and low-productivity subsistence farming to more profitable commercial agriculture (Timmer 1988; von Braun and Kennedy 1994; Heltberg and Tarp 2002), which in turn can stimulate the rural economy of developing countries (Binswanger and von Braun 1991; von Braun 1995). A first step in this direction is to increase their participation as sellers of staple food grains. Most smallholders grow staples for household consumption, and investment in staple food production poses lower risk as compared to investment in cash crops or other high value crops (Pingali et al. 2005; Jaleta et al. 2009). Yet, less than 50% of smallholder farmers in many countries of sub-Saharan Africa (SSA) participate in staple food grain output markets as sellers (see, e.g., Alene et al. 2008 for Kenya; Barrett 2008 for a survey of the literature covering several countries in eastern and southern Africa; and Mather et al. 2013 for Kenya, Mozambique and Zambia). In their pioneering work, de Janvry et al. (1991) explain that low market participation by smallholders in agricultural markets is a household-specific market failure that results from high transaction costs of accessing markets. Subsequent literature has provided empirical evidence that high transaction costs arising from poor road infrastructure and inadequate market information can reduce market participation (Goetz 1992; Key et al. 2000; Heltberg and Tarp 2002). More recent evidence shows that improved access to public goods (roads, extension, and communication services) and private assets (land, labor, and animal traction) can also facilitate market participation (Renkow et al. 2004; Cadot et al. 2006; Boughton et al. 2007). However, relatively little attention has been paid to the potential role of factor market imperfections that may undermine the capacity of a household to generate a marketable surplus (Alene et al. 2008; Mather et al. 2013). We address some of this gap in the literature by focusing on the liquidity constraints faced by households during the production period.

Due to the seasonality of agriculture, farmers have competing demands for cash received at the time of harvest, with meeting consumption needs often being the most prominent (Stephens and Barrett 2011; Burke et al. 2019). This leaves limited resources to be spent on crop productivity-enhancing inputs (Duflo et al. 2011; Dercon and Christiaensen 2011), which in turn is expected to reduce output supply and thus the marketable surplus. The lack of well-functioning credit markets in many developing countries further exacerbates this problem. While prior literature shows that liquidity constraints lead to lower agricultural production (Feder et al. 1990; Foltz 2004; Winter-Nelson and Temu 2005), there is lack of rigorous research linking liquidity constraints *during the production period* to a household's likelihood of market participation as a seller.[1 2]

Another less explored aspect of smallholder market participation in the developing country context is the choice of marketing channel that households make when faced with several buyer types, such as private traders of various scales, government agencies, and other households in the community. The pioneering literature in this field has been dominated by discussion of the choice to sell at the farmgate versus at a distant market, and predominately focuses on commercial crops or largely commercialized markets (Fafchamps and Hill 2005; Shilpi and Umali-Deininger 2008; Zanello et al. 2014; Negi et al. 2018). In reality, households may face several buyer types, each with their associated constraints and opportunities. Further, the discussion of semi-commercialized food grain markets requires recognition of non-separability of production and consumption decisions if there are multiple market failures. Very few papers (e.g., Muamba (2011) and Takeshima and Winter-Nelson (2012)) study the choice between selling at the farmgate versus at a distant market when production and consumption decisions are not separable. In this article, we examine whether the choice of marketing channel is affected by liquidity constraints faced during the production period. We argue that liquidity constraints will affect marketable surplus, which in turn will affect the household's ability to take advantage of relatively more remunerative marketing channels.

The article makes four main contributions to literature. First, it generates empirical evidence about whether and to what extent liquidity constraints during the production period affect food grain market participation and sellers' choice of marketing channel. Second, it adds to the

[1] The literature on smallholder grain market participation has extensively investigated a slightly different aspect of the problem, namely the influence of liquidity constraints *during the marketing period* (i.e., after the marketable surplus has been realized) to explain the "sell low, buy high" phenomenon (Stephens and Barrett 2011; Dillon 2017; Burke, Bergquist, and Miguel 2019). Smallholder farmers are found to sell food grains relatively soon after harvest due to cash constraints and/or lack of quality storage facilities. At this time of the year, food grain prices tend to be at their lowest ("sell low"). Many of these households then purchase grain later in the marketing year, when grain prices tend to be higher ("buy high").

[2] Liquidity constraints that affect investments in the production period are likely to be correlated with several other household characteristics such as land holding size, household assets, and household labor. The effect of these on market participation has been explored earlier, although no attempt was made at a causal analysis (Renkow et al. 2004; Cadot et al. 2006; Boughton et al. 2007; Mather et al. 2013). More importantly, the liquidity constraints that we consider in this analysis differ from these household characteristics because the former can vary significantly over short periods of time due to a sudden loss in income and/or poor crop harvest, while the latter are more or less fixed in the short run. Additionally, liquidity constraints (or the lack thereof) capture sudden changes in household incomes that are not controlled by these fixed household characteristics.

thin literature on farmers' marketing channel choice when production and consumption (and thus marketing) decisions are non-separable. Third, it provides a rigorous conceptual framework that helps illustrate the mechanisms through which liquidity constraints during the production period may affect farmers' choices regarding market participation and marketing channel; this framework guides the specification of our empirical models. Finally, this paper provides empirical evidence on the relatively less researched link between constraints faced in agricultural production and smallholder access to remunerative markets for agricultural goods in a developing country context.

We address the literature gaps noted above using Zambian smallholder maize-growing households as a case study. Zambia has a considerably large agricultural sector that employs 49% of the country's population (World Bank 2019a). Maize is the main staple food grain in Zambia, is grown by almost all smallholder households, and is an important source of income for many of them (Chapoto et al., 2015). However, maize market participation as a seller is far from universal.[3] Credit markets in rural Zambia are poorly developed. In the 2013/14 agricultural season only 19% of rural households reported acquiring credit for agriculture from any formal or informal source. In a recent experimental study conducted by Fink, Jack, and Masiye (2020) for rural Zambia, the authors find almost universal (98%) uptake of lean season loans at an implicit interest rate of 4.5% per month, indicating severe cash needs among agricultural households.

Smallholders' choice of marketing channel is of particular interest for Zambia given the important role played by the country's maize marketing board, the Food Reserve Agency (FRA).[4] During the study period, the FRA bought maize from farmers at its depots throughout the country at a pan-territorial price that was higher than the average market price. Previous studies have shown that the FRA's activities have raised the mean level and reduced the variability of maize market prices (Mason and Myers 2013), which has induced farmers to bring more land under maize cultivation (Mason, Jayne and Myers 2015). Previous work has also shown that the FRA's activities benefit smallholders who sell to it but have very limited spillover effects on the remaining population and may in fact hurt maize net buyers (Mason and Myers 2013; Fung et al. 2020).

[3] In the maize marketing years covered in this analysis (2011/12 and 2014/15), the percentage of maize growers who sold more maize than they purchased (maize net sellers) was 52% and 42%, respectively.

[4] The FRA is a parastatal that serves as a strategic food reserve and maize marketing board; it seeks to raise and stabilize maize market prices as a means of improving national food security and farmer incomes. During the period of analysis for this study (2010-2015), the FRA played a major role in maize marketing in Zambia and purchased an average of 75% of the total volume of maize sold by smallholders each year (Fung et al. 2020).

Justifications made for the activities of grain marketing boards like the FRA typically include the presence of uncompetitive grain markets and high transaction costs in remote areas. However, recent evidence shows that the argument of widespread uncompetitive food markets in rural SSA may be unsubstantiated and that market access has improved significantly (Chamberlain and Jayne 2013; Sitko and Jayne 2014; Dillon and Dambro 2017).[5] On the other hand, long payment delays by the FRA to farmers is a perennial problem, as is the significant uncertainty each year regarding the timing and scale of FRA's maize purchases, making it a less viable marketing channel for vulnerable and liquidity constrained households. The FRA has also been criticized for: (i) crowding out private maize traders, who provide an essential service to smallholders by providing timely maize market access and payments; and (ii) accounting for a large share of the scarce government resources available for the agricultural sector (Jayne et al. 2011; Sitko and Jayne 2014). Thus, this article has important implications for resource allocation and the maize market policies pursued by the Zambian government and other governments in the region.

1.2 Conceptual Framework

We use the framework of a non-separable agricultural household model and assume that production, consumption, and initial marketing decisions are made simultaneously at the time of planting (Singh, Squire, and Strauss 1986; Key et al. 2000). However, once agricultural output has been realized and harvest-time prices are revealed, the household can update its marketing decisions.

Let a potentially risk-averse agricultural household maximize its expected utility of consumption of maize (c_{mz}), leisure (c_l), and market-purchased goods ($\boldsymbol{c_{mk}}$), given household level characteristics ($\boldsymbol{z^h}$) that affect consumption tastes and preferences and subject to several constraints. (See Appendix 1A for the complete model.) For simplicity, we assume maize to be the only agricultural product produced by the household. We explicitly model liquidity constraints during the production period and assume that the liquidity constraints apply only to the variable production inputs (labor (l) and non-labor variable inputs ($\boldsymbol{x}$)). Following de Janvry et al. (1992), the input purchase liquidity constraint can be represented as $\eta(\boldsymbol{p_x x} + wl - K) = 0$, where w and

[5] Sitko and Jayne (2014) find that even the remotest villages in Zambia were visited by at least one private maize trader during the peak maize marketing season and that private traders made only small marketing margins through maize transactions, an important indicator of competitive markets. Similarly, Chamberlain and Jayne (2013) find that private trader activity was higher, and distance travelled by smallholders for crop sales was lower in areas where public marketing boards reduced their activity.

$\boldsymbol{p}_x$ denote the prices of labor and non-labor inputs, respectively. η is the shadow price of liquidity and *K* represents the household's available cash. Thus, for liquidity constrained (LC) households, liquidity is a binding constraint ($\boldsymbol{p_x x} + wl - K = 0$ and $\eta > 0$) and the value of agricultural inputs used will be limited by some upper limit *K* that represents the household's available cash. On the other hand, if the household is not liquidity constrained (UC), the constraint is no longer binding ($\boldsymbol{p_x x} + wl - K < 0$ and $\eta = 0$) and purchases of inputs are not limited by *K*. LC and UC households will then maximize their expected utility under different sets of constraints, and thus have different input demand and output supply functions:

(1a) $\boldsymbol{q^{LC}} = \boldsymbol{q^{LC}}(p_e, \boldsymbol{p_{mk}}, w(1+\eta), p_x(1+\eta), K, \boldsymbol{z^h}, \boldsymbol{z^q})$

(1b) $\boldsymbol{q^{UC}} = \boldsymbol{q^{UC}}(p_e, \boldsymbol{p_{mk}}, w, p_x, \boldsymbol{z^h}, \boldsymbol{z^q})$

Here, $\boldsymbol{q^{LC}}$ and $\boldsymbol{q^{UC}}$ denote the vector of input demand and output supply functions for LC and UC households, respectively; p_e is the household's expectation, as of planting time, of the maize price that will prevail at harvest time; $\boldsymbol{p_{mk}}$ is the vector of prices for other market purchased consumption goods; and $\boldsymbol{z^q}$ is a vector of fixed and quasi-fixed factors affecting production. $(1+\eta)$ represents an implicit input price markup for households that are liquidity constrained. An important implication of this result is that LC households would use fewer inputs and produce less output than unconstrained households, *ceteris paribus* ($\boldsymbol{q^{LC}} < \boldsymbol{q^{UC}}$).

Let p_m be the realized price of maize at harvest and τ be household-specific transaction costs involved in marketing maize such that $\tau > 0$. These transaction costs are added to the market price of maize if the household is a buyer of maize and subtracted from the price of maize received if the household is a seller of maize (Key et al. 2000). Thus, the household-specific buyer and seller prices can be represented as $p_b = (p_m + \tau)$ and $p_s = (p_m - \tau)$, respectively. Let $p_a(q_{mz}, \boldsymbol{z^h})$ be the household's shadow price of maize that is a function of the household's maize output (q_{mz}) and other household characteristics ($\boldsymbol{z^h}$). We assume that $p_a(q_{mz}, .)$ is a function strictly decreasing in q_{mz}. Thus, since LC households produce less maize ($q_{mz}^{lc} < q_{mz}^{uc}$), they would have a higher shadow price of maize than UC households (i.e., $p_{lc}^{a} > p_{uc}^{a}$). The household's maize market position will be determined as follows: the household sells maize if $p^s \geq p^a$; it buys maize if $p^b \leq p^a$; and it is autarkic with respect to maize if $p^b > p^a > p^s$.

Based on this discussion, we state the following hypotheses:

Hypothesis 1: Liquidity-constrained maize-producing households are less likely to become maize sellers, all else remaining constant, as compared to unconstrained households because $\Pr[p_{lc}^{a} \leq p^{s}] < \Pr[p_{uc}^{a} \leq p^{s}]$.

Hypothesis 2: A liquidity-constrained household's probability of selling maize will be less responsive to changes in expected prices. We expect this because the liquidity constraint limits a household's capacity to increase production in response to higher expected prices, i.e. $\frac{\partial \Pr[p_{lc}^{a} \leq p^{s}]}{\partial q_{mz}^{lc}} \cdot \frac{\partial q_{mz}^{lc}}{\partial p_e} < \frac{\Pr[p_{uc}^{a} \leq p^{s}]}{\partial q_{mz}^{uc}} \cdot \frac{\partial q_{mz}^{uc}}{\partial p_e}$, because $\frac{\partial q_{mz}^{lc}}{\partial p_e} < \frac{\partial q_{mz}^{uc}}{\partial p_e}$.

The third hypothesis links liquidity constraints during the production period with the marketing channel chosen by maize sellers. Similar to the case of market position, we assume that the choice of marketing channel is determined after maize output has been realized. Further, we assume that the choice of marketing channel is conditional on the decision to participate in the maize market as a seller. We continue to assume (as we did above) that the household is potentially risk-averse and thus motivate the problem from an expected utility maximization perspective. Let $V_j\left(p_j^s m - F_j;\ \boldsymbol{z^h}\right)$ be the expected utility obtained from selling to marketing channel j. Here, p_j^s represents the *effective* price received from selling maize to channel *j*. The effective price incorporates transaction costs incurred in transporting and handling each unit of maize and also discounts the price by the expected delay in market entry and/or in payment by the buyer. *m* is the quantity of maize marketed by the household to channel *j*. F_j is a fixed transaction cost associated with the use of channel *j*. This may include search and negotiation costs specific to that channel, such as membership in a cooperative or farmer group that facilitates the collection and transport of maize in bulk from the village to market or FRA depot, and uncertainty related to specific channels (like the FRA). This essentially implies that to be able to sell to channel *j*, a household must be marketing enough maize such that $p_j^s m > F_j$, *ceteris paribus*. Given this background we state our third hypothesis as follows:

Hypothesis 3: Since LC households are expected to produce less maize ($q_{mz}^{lc} < q_{mz}^{uc}$), they are expected to sell less and thus be less likely to overcome the high fixed costs incurred in selling to channels such as the FRA, i.e., $\Pr\left[V_{FRA} - V_j > 0|LC\right] < \Pr\left[V_{FRA} - V_j > 0|UC\right]$, where *j* is any other marketing channel. Thus, we expect LC households to be less likely than UC households to sell to the FRA.

1.3 Data

The main data source used in this analysis is the Rural Agricultural Livelihoods Survey (RALS), a three-wave nationally representative panel survey dataset of smallholder farm households in Zambia. We utilize the first and second waves of the RALS data.[6] These waves were implemented in June-July of 2012 and 2015, respectively, by the Indaba Agricultural Policy Research Institute (IAPRI) in collaboration with the Zambian Central Statistical Office (CSO) and the Ministry of Agriculture (MoA). See CSO (2012) for details on the RALS sample design. The dataset contains detailed information on household demographics, crop and livestock production and marketing, off-farm employment and own business activities, and distances to roads, markets, and public services. The 2012 survey covered the 2010/11 agricultural year (October 2010–September 2011) and the associated crop marketing year (May 2011–April 2012). The 2015 survey covered the 2013/14 agricultural year and the 2014/15 crop marketing year.

A total of 8,839 households were interviewed in the 2012 RALS. Of these, 7,254 (82%) were successfully re-interviewed in 2015. Our analytical sample consists of the balanced panel of 6,063 RALS households that grew maize in both 2012 and 2015, and thus a total of 12,126 household-year observations. Our analytical sample contains 84% of the total household-year observations in the full balanced panel (14,508 observations). Tests for attrition bias based on a procedure recommended by Wooldridge (2010) – described in detail in Appendix 1B – fail to reject the null of no attrition bias for all outcome variables except one (maize market position). We suspect that this exception is due to our inability to control for time-constant unobserved heterogeneity in these tests – something that we are able to control for in the main analysis, the methods for which are described below). We therefore do not consider attrition bias to be a major cause of concern in our analysis.

The explanatory variables obtained from RALS are briefed here. The prices of inorganic fertilizer and seed as well as the agricultural wage rate (the price to weed 0.25 ha) are used to control for agricultural input prices ($\boldsymbol{p_x}$ and w in the conceptual framework). Distances to important points of market access such as the nearest tarmac and feeder roads, and agricultural market are used as proxies for transaction costs (τ). We also include the number of maize traders that arrived in the village during the peak maize marketing season (May-October) to capture the

[6] Data from the third wave, which was conducted in June-July 2019, were not available for analysis at the time of this study.

competitiveness of and access to markets within the village (as suggested by Chamberlain and Jayne (2013) and Sitko and Jayne (2014)). Dummy variables that indicate the household's ownership of a bicycle, radio, and cellphone are included to represent the household's capacity to reduce fixed transaction costs such as those associated with obtaining price and buyer information. Land, livestock (measured as tropical livestock units (TLUs)), and number of plows, harrows, and ox-carts owned by the household are used to control for the household's quasi-fixed factors of production ($\boldsymbol{z^q}$).[7] Controls for household characteristics affecting consumption ($\boldsymbol{z^h}$) include household size (the number of full-time adult equivalent household members) and various characteristics of the household head (age, education, and sex).

We use district-level data on retail maize prices collected by the CSO (CSO 2018) to compute maize market prices. Even though the RALS records price data for each maize transaction made by a household, we refrain from using this information to avoid bias due to incidental truncation.[8] Maize market prices in Zambia are also significantly affected by the government's market interventions through the FRA (Mason and Myers 2013). We do not explicitly model the interdependence of market and FRA prices; rather we include separate variables for the FRA and market prices. For each of these, we compute estimates of each household's expected (p_e) and realized post-harvest (p_m) maize price. For the former, we assume naïve expectations. More specifically, we use the district-level retail maize price as of August of the marketing season just before the agricultural season in question as the expected market price of maize.[9] Similarly, the FRA price during the previous marketing year is used as a proxy for a household's expected FRA price. The district-level maize retail price in August of each harvest year is used as the realized post-harvest maize market price. The post-harvest FRA price is simply that paid by the FRA during each harvest year. The district-level retail and pan-territorial FRA prices are adjusted for

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[7] TLUs were calculated as follows, following FAO (2007): cattle = 0.70, sheep and goats = 0.10, pigs = 0.20 and chickens = 0.01.

[8] Since the price information in RALS was only recorded for households that sold maize, these prices may not accurately reflect the prices faced by all households. Any resulting measurement errors may in turn be systematically correlated with unobservables that determine market participation.

[9] Zambia's marketing season runs from May to April and the agricultural season runs from October to September. The naïve expectation maize price as of October 2010 is set as the retail price of maize as of August 2010. We used the prices as of August because in our sample the largest share of maize transactions (46%) was made during the month of August, followed by July (20%) and September (14%). It could be a matter of concern that August prices do not represent the true price faced or expected by the household. We conduct sensitivity analysis using two other measures of prices. These are discussed later in the article.

transportation costs (obtained from the RALS) to generate farmgate prices. See Appendix 1C for further details.

Zambian smallholder production is almost exclusively rainfed, and so rainfall is an important determinant of agricultural output levels. Thus, we include information on total rainfall and moisture shocks during the growing season as well as their long-term averages (a 16-year moving average).[10] A moisture shock in the season before the planting season of interest was used as the exclusion restriction for liquidity status (discussed further below). These variables were obtained from data compiled by Snyder et al. (2019) using geospatial data from Tropical Applications of Meteorology using Satellite data and ground-based observations (TAMSAT) (Maidment et al. 2014; Tarnavsky et al. 2014; Maidment et al. 2017). Snyder et al. (2019) matched the TAMSAT data to GPS locations of RALS households and created rainfall estimates using the Raster Calculator tool in ArcGIS Model Builder. The TAMSAT data has a spatial resolution of approximately 0.0375 x 0.0375 degrees, which is approximately 4 x 4 kilometers, or 16 square kilometers (Snyder et al. 2019). In practical terms, these estimates are approximately village-level measures.

Finally, the consumer price index from the World Bank (2019b) was used to convert all prices from nominal to real terms (with base year 2017=100). This implicitly controls for variation in the prices of consumer goods ($\boldsymbol{p_{mk}}$). See Table 1D.1 in Appendix 1D for descriptive statistics for all variables.

1.4 Important definitions

In this section we describe three variables that are an integral part of the analysis: variables that capture the household's liquidity status during the production period, their maize market position, and the maize marketing channel chosen by net sellers for their largest transaction.

1.4.1 Liquidity status

Liquidity is a difficult concept to measure because it is not easily observable. It is often also confused with a similar but slightly different concept of credit constraint/access (Winter-Nelson and Temu, 2005). Further, different types of liquidity constraints can affect different household decisions such as production of farm and non-farm goods, and consumption of market

[10] Moisture shock is defined here as the presence of more than one moisture stress period during the maize growing season. Moisture stress is defined as in Snyder et al. (2019) as the number of overlapping 20-day periods with less than 40 mm of rainfall. Kusunose et al. (2020) use a similar weather shock variable as an instrument for liquidity.

and home-produced goods (Sadoulet and de Janvry 1995). In this article, we focus on liquidity constraints that result in a lack of sufficient cash to enable the household to invest in productivity enhancing agricultural inputs. We follow an approach similar to Winter-Nelson and Temu (2005) and exploit unique data available in RALS to define a household to be liquidity constrained during the production period if one or both of the following criteria are met: (1) the household claims to not have acquired fertilizer from the market due to a lack of cash; and/or (2) the household claims to not have obtained fertilizer from the Farmer Input Support Program (FISP) due to (a) not being able to afford the farmer's down payment for obtaining fertilizer through FISP, and/or (b) not being able to afford membership in a cooperative or other farmers' group, as required for participation in the program.[11, 12]

A natural concern with a stated preference measure of liquidity such as the one used here is hypothetical bias – i.e., households overstating the liquidity constraints that they face. It may be that households imprecisely state as 'lack of cash' other constraints, such as poor returns to or low profitability of fertilizer use, that keep them from purchasing fertilizer. We alleviate these concerns through some additional analysis. First, the RALS survey instrument included a rich set of alternatives into which the respondent's main reason(s) for not purchasing fertilizer from the market or not obtaining fertilizer from FISP could be coded.[13] While lack of cash was the leading reason for not purchasing fertilizer from the market (80%), low profitability of fertilizer use (7%), and adequate soil fertility (6%) were the other most common reasons mentioned by these households. Similarly, apart from the lack of cash (27% could not afford the FISP down payment and 15% could not afford cooperative membership), not being eligible for FISP (17%) was the leading reason for not being able to obtain FISP fertilizer. (See Tables 1D.2 and 1D.3 in Appendix 1D.)

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[11] FISP is a large-scale government program designed to enable eligible farmers to obtain farm inputs at subsidized prices. Eligibility is primarily determined by landholding, membership in a farmer cooperative and payment for part of the cost for inputs received (Mason, Jayne, and Mofya-Mukuka 2013). During the study period, the program focused on maize inputs (inorganic fertilizer and improved seed). Since the 2015/16 agricultural year, the FISP has been partially converted to a flexible electronic voucher (e-voucher) program (Kuteya, Chinmaya, and Malata 2018) with aims to crowd-in private sector participation in Zambia's agricultural input value chains and give farmers more flexibility in terms of the farm inputs or equipment for which they can use the e-voucher.

[12] According to Burke, Jayne, and Sitko (2012) the cash outlays required for obtaining inputs from FISP could cost up to 20% of the annual gross income for 60% of the smallholders in Zambia, thus precluding many smallholders from being able to participate in FISP. In fact, evidence suggests that FISP has benefitted wealthier farmers proportionately more than poorer farmers (Mason, Jayne, and Mofya-Mukuka 2013).

[13] Respondents could list more than one reason for not being able to purchase fertilizer from the market or obtain fertilizer from FISP. We use the reason specified by the respondent as the most important one.

Secondly, we expect the scope of bias to be less for criterion 2 than criterion 1 because liquidity constraints are likely to be severe for farmers who are unable to afford FISP down payments and/or membership fees for cooperatives and farmer organizations. Thus, we use criterion 2 alone as an alternative definition of liquidity constrained households and conduct robustness checks to validate the results.

Finally, we expect that being liquidity constrained is correlated with other characteristics of the household, such as ownership of land, livestock, assets, access to markets, non-farm income, and use of agricultural inputs. The better measure of liquidity status would be the one that provides a sharper separation between households based on these characteristics. We computed the differences in mean values for key variables between LC and UC households, where we used three different definitions of LC: criterion 1 only, 2 only, and criteria 1 or 2 (see Table 1D.4 in Appendix 1D). We note that using the third definition gives the largest mean differences between LC and UC households in a majority cases; these differences are statically significant at the 1% level of significance across all characteristics except for distance to feeder road. We thus choose to employ criteria 1 or 2 as the main definition of liquidity status.

Approximately 62% and 52% of households were liquidity constrained in the RALS 2012 and 2015 waves, respectively, using this approach (Table 1.1, column A). 13% of households that were UC in RALS 2012 became LC in the next round, whereas 23% of those that were LC in 2012 became UC in RALS 2015 (Table 1D.5, Appendix 1D). Most of the households were defined as LC as a result of meeting criterion 1; relatively fewer met criterion 2 (Table 1.1, column C). Only 23% and 15% of sample households met both criteria in RALS 2012 and 2015 (Table 1.1, column D), respectively.

Table 1. 1: Percentage of Liquidity Constrained Households, by RALS wave and Criteria

RALS wave	Criteria 1 or 2	Criteria 1 only	Criteria 2 only	Criteria 1 & 2
	A	B	C	D
2012	62%	57%	26%	23%
2015	52%	47%	18%	15%

Notes: Sample consists of maize growing households in the balanced panel in each wave (N=6063).
368 households that claimed to be LC according to Criteria 2 purchased >100 kg of fertilizer from the market. We re-defined these households as UC.

1.4.2 Maize market position

In our sample, a small percentage of households (13%) both buy or sell some amount of maize grain or maize meal, and 21% of households neither sell nor buy any maize product.[14] This implies that it is not straightforward to classify these maize-growing households as maize sellers or buyers. Following an approach similar to Bellemare and Barrett (2006) and Burke, Myers, and Jayne (2015), we therefore define three mutually exclusive maize market positions as follows. A household is defined as a maize *net seller* if the quantity of maize sold is greater than the quantity of maize grain and maize meal purchased, *autarkic* if the household has no maize sales and purchases, and a *net buyer* if the quantity of maize sold is less than the quantity of maize grain and maize meal purchased.[15] During the 2014/15 (2011/12) marketing year only 38% (42%) of LC households are classified as maize net sellers compared to 67% (67%) of UC households (see Table 1D.6 in Appendix 1D).

An alternative definition of maize market positions was computed using value (instead of quantity) of maize and maize meal sold and bought. Maize sold was valued at the district median maize producer price (computed from prices reported by maize-selling households) in order to minimize the effect of outliers. Similarly, maize grain and maize meal purchased by the household was valued at the district level median (computed from household-reported purchase price data). According to this definition, only 31% (44%) of LC households were maize net sellers in 2014/15 (2011/12) as compared to 56% (68%) for UC households (see Table 1D.7 in Appendix 1D). This value-based maize market position was used for conducting robustness check.

1.4.3 Maize marketing channels

Smallholder households in Zambia sell maize to a wide variety of buyers. Although some sell to more than one type of buyer, the vast majority of maize net sellers (87% in 2011/12 and 88% in 2014/15) had only one maize sale transaction in a given marketing year. For tractability, we focus on the largest maize sale made by each household (in quantity terms), and we group maize marketing channels into four categories: the FRA, small scale private traders, large scale private traders, and other households.

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[14] Maize meal is a type of maize flour and is used to prepare *nshima*, the most common form in which maize is consumed in Zambia.

[15] To compute the maize market positions, the maize meal bought by a household was first converted to its equivalent maize grain quantity using conversion factors from Mwiinga et al. (2002).

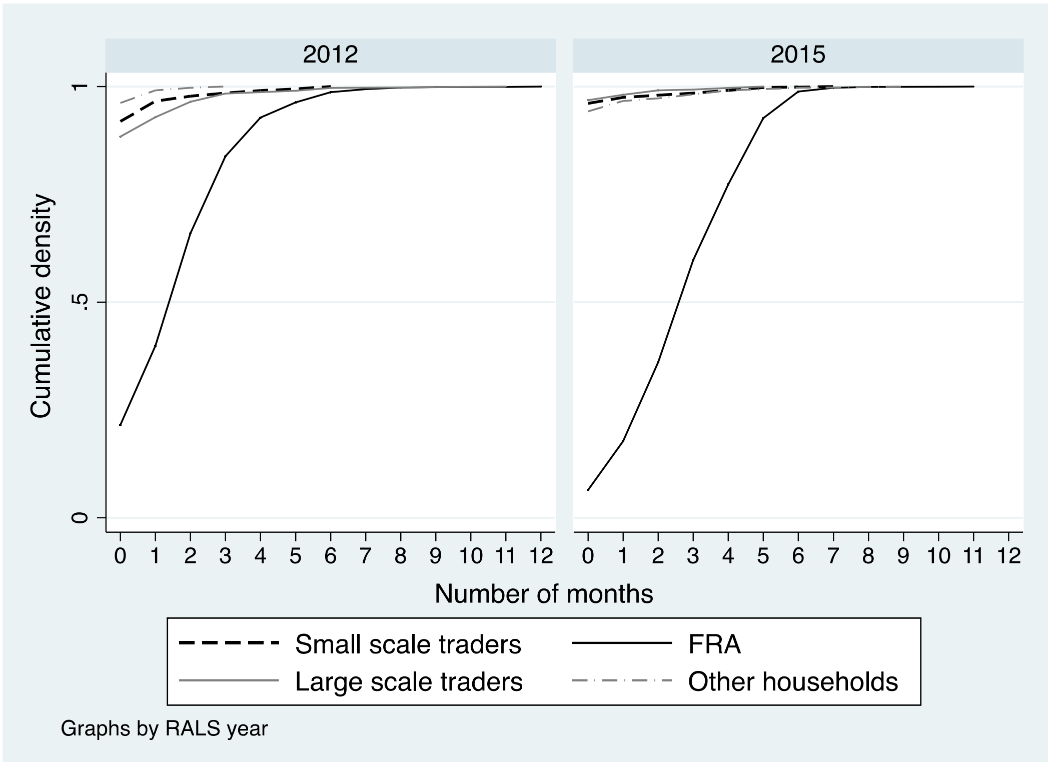
In the 2014/15 (2011/12) marketing year, and focusing on the largest transaction, 48% (64%) of net seller households chose to sell maize to the FRA, 26% (17%) sold to a small-scale trader, 16% (10%) sold to a large-scale trader, and 11% (9%) to another households (Table 1D.8 in Appendix 1D). A smaller percentage of LC households sold to the FRA as compared to UC households in both years. Almost 90% of the households selling to the FRA had to travel more than 1 km to make the maize sale. In contrast, 74% (64%), 33% (30%), and 87% (85%) of the transactions made to small scale traders, large scale traders, and other households in 2011/12 (2014/15) were made at the farmgate, respectively (Tables 1D.9 and 1D.10 in Appendix 1D). The median farmgate price received from the FRA was 42% (24%) higher than the price received from small scale traders in the 2011/12 (2014/15) marketing year. The median price received for sales to other households was also slightly higher (1% and 8% for 2011/12 and 2014/15 respectively) than that for small scale traders (Tables 1D.9 and 1D.10 in Appendix 1D). This is probably because maize sales to other households were spread more evenly over the maize marketing season and thus the prices received from this channel would reflect, in part, the higher maize prices that prevail later in the marketing season.[16]

Even though the price offered by the FRA during our period of analysis was higher than average private market prices, there was considerable uncertainty each season about when the FRA would start buying maize and when farmers would be paid. For example, almost 50% of farmers who sold to the FRA had to wait for at least two months to be paid. In contrast, more than 90% of those who sold to private traders, or another household received payment at the time of the sale (Figure 1). Furthermore, even though maize harvesting begins in May, farmers typically have to wait until July or August for the FRA to start buying maize. The combination of the uncertain timing of FRA maize purchases and FRA payment delays would likely lead households to discount considerably the price offered by the FRA, especially for households that may be in urgent need of cash. Another potential constraint that smallholder households may face in selling to the FRA is that, officially, 500 kg is the minimum amount of maize that the FRA will buy from an individual or cooperative (Mason 2011), yet the median quantity of maize sold by LC households in our

[16] Figure D2 in Appendix D shows that >50% of the largest maize transactions to other households occur in months *other than* July, August, and September (the peak maize marketing months). This is in comparison to <10% for FRA and <40% for small- and large-scale private traders.

sample was only 50 kg. However, farmers can overcome this hurdle by bulking their product with that of other farmers.

Figure 1. 1: Number of months between sales transaction and payment to farmer for the largest maize transaction



1.5 Estimation

Estimation is carried out in three main steps, as described in this section.

1.5.1 Step 1

We first estimate the effects of liquidity constraints and changes in expected maize prices on maize output using a linear switching regression. This approach allows the parameter estimates to differ between LC and UC households, in line with the conceptual framework where LC and UC households were found to solve different optimization problems, similar to previous work on liquidity constraints (Feder et al. 1990; Foltz 2004; Winter-Nelson and Temu 2005).[17] The availability of panel data enables us to control for unobserved time-invariant household-level heterogeneity. Given the non-linear-in-parameters nature of our estimators in the second step regression (discussed below), we use a correlated random effects (CRE) approach (Mundlak 1978;

[17] We also estimate the equation using a 2SLS approach as a robustness check, as will be discussed later.

Chamberlain 1984) to control for household-level heterogeneity throughout the paper. Within this context, CRE provides consistent estimates, unlike the fixed effects approach.[18] [19] In our analysis, we operationalize CRE by including the means of all time-varying exogenous variables as additional regressors in our model. There may be time-varying unobservables (such as an unreported access to productive resources from family or friends) that are correlated with both a household's liquidity status and their maize output, which can potentially result in omitted variables bias. To test for such endogeneity (and to correct for it, if present), we use a two-step control function endogenous switching CRE-pooled ordinary least squares (CRE-POLS) procedure as suggested by Wooldridge (2015) and Murtazashvili and Wooldridge (2016). This two-step approach entails estimating a first stage regression in which liquidity status is the dependent variable and the explanatory variables include all of the explanatory variables from the main equation and an instrumental variable that affects a household's liquidity status but has no effect on the household's maize output except through its effect on liquidity status. (See the Identification section below for a discussion of the instrument used in this study.) The residuals from this regression are then included as an additional regressor in the main equation. If the residuals are statistically significant, then we reject the null hypothesis of exogeneity of the liquidity status variable and focus on the two-step control function endogenous switching CRE-POLS model results for inference (because it corrects for endogeneity, conditional on the validity of the instrument). If the residuals are not statistically significant, then we fail to reject the null hypothesis of exogeneity and focus on the exogenous switching CRE-POLS model results for inference. Details on the approach and the estimating equation are discussed below. Equation 2 represents the main equation to be estimated:

$$(2)\quad q_{mz,it} = LC_{it} \times \boldsymbol{X}_{1it}\boldsymbol{\beta}_1 + \boldsymbol{X}_{1it}\boldsymbol{\beta}_0 + LC_{it} \times c_i + c_i + LC_{it} \times v_t + v_t + \tau_1 LC_{it} \times \widehat{u_{it}} + \tau_0 \widehat{u_{it}} + \epsilon_{it}$$

[18] The fixed effect approach is not recommended for non-linear-in-parameters panel estimation when the number of observations of the individual (N) tends to infinity, but the number of time periods (T) is very small. Using a fixed effects approach would require estimating parameters for each of the N units which are known be inconsistent. This is known as the incidental parameters problem (Greene et al. 2002; Arellano and Hahn 2007).

[19] Like a fixed effects or (regular) random effects approach, a key assumption underlying the CRE approach is strict exogeneity of the observed covariates, conditional on the unobserved household-level time constant heterogeneity. However, the CRE approach allows the observed covariates to be correlated with the unobserved heterogeneity as in the fixed effects approach, whereas the regular random effects approach assumes these two are uncorrelated.

Here, $q_{mz,it}$ is the maize output of household *i* in agricultural year *t*, LC_{it} is an indicator variable that equals 1 if the household was liquidity constrained during the production period, and 0 if not. $\boldsymbol{X}_{1it}$ is the vector of explanatory variables (including the vector of expected harvest-time maize prices ($\boldsymbol{p_e}$), prices of agricultural inputs ($\boldsymbol{p_x}$ and w), household characteristics ($\boldsymbol{z^h}$), quasi-fixed factors ($\boldsymbol{z^q}$), and rainfall and moisture shocks in the growing season). c_i represents household-specific time invariant unobserved heterogeneity, v_t is the year fixed effect, $\widehat{u_{it}}$ are the residuals from the first stage regression of the liquidity status, and ϵ_{it} is the idiosyncratic error specific to each household and time period. $\boldsymbol{\beta}_1$, $\boldsymbol{\beta}_0$, τ_1, and τ_0 are the parameter values to be estimated.[20] The estimates of interest are the difference in expected maize output between LC and UC households ($E(q_{mz}|LC = 1) - E(q_{mz}|LC = 0)$) and the marginal effect of an increase in expected maize prices on maize output for LC and UC households ($E\left[\frac{\partial q_{mz}}{\partial \boldsymbol{p_e}} \mid LC = 1\right]$ *and* $E\left[\frac{\partial q_{mz}}{\partial \boldsymbol{p_e}} \mid LC = 0\right]$).

1.5.2 Identification

The first stage liquidity status regression is estimated using a CRE-linear probability model and is a regression of liquidity status (LC_{it}) on the full set of exogenous variables ($\boldsymbol{X}_{1it}$) and an exclusion restriction (z_{it}):

(3) $LC_{it} = \boldsymbol{X}_{1it}\boldsymbol{\alpha}_1 + \alpha_2 z_{it} + c_i + v_t + u_{it}$

Identification hinges on the availability of a strong exclusion restriction – i.e., a variable that has a strong statistically significant effect on the household's selection into one of the two liquidity status regimes, yet which we can confidently assume is not correlated with the household's maize output through any channel other than its effect on liquidity status. Our exclusion restriction is an indicator variable that equals one if the village in which the household resides experienced a moisture shock in the growing season prior to the planting season in which we measure maize output and the liquidity constraint. A moisture shock in year t-1 is expected to lead to poor crop output and thus a higher chance of being liquidity constrained in the following year (Kusunose et al. 2020). We find that a moisture shock in year t-1 is strongly partially correlated with being

[20] Failure to reject that τ_0=0 and τ_1=0 indicates that we fail to reject that liquidity status is exogenous to maize output and can thus use an exogenous version for the main analysis (we call this a CRE-exogenous switching regression). Alternatively, rejecting that at least one of the τ is equal to zero would imply that liquidity status is endogenous; the inclusion of the first stage residuals corrects for this endogeneity (conditional on the validity of the exclusion restriction). We refer to this as the CRE-endogenous switching regression.

liquidity constrained in year t (F-statistic = 16.27, p-value = 0.0001; see Table 1E.1 in Appendix E for the full results). Additionally, a moisture shock in year t-1 should not affect maize output in year t through any channel other than its effect on liquidity, particularly after controlling for rainfall conditions and the other covariates in year t, as well as time-constraint unobserved heterogeneity via CRE. The validity of the instrument is further discussed later in the article and probed via robustness checks.

1.5.3 Step 2

In the second step we estimate the effect of changes in maize output on the household's maize market position using a CRE-ordered probit approach. The respective probabilities of being a net buyer and net seller of maize are given as follows:

(4) $Pr(M_{it} = 1 | \, q_{mz,it}, \, \boldsymbol{X}_{2it}, \, c_i, \, v_t) = \Phi(0 - (\delta q_{mz,it} + \boldsymbol{X}_{2it}\boldsymbol{\gamma} + c_i + v_t))$

(5) $Pr(M_{it} = 3 | \, q_{mz,it}, \, \boldsymbol{X}_{2it}, \, c_i, \, v_t) = \Phi(\delta q_{mz,it} + \boldsymbol{X}_{2it}\boldsymbol{\gamma} + c_i + v_t)$

where M_{it} is the household's maize market position (M_{it} =1 if net buyer, =2 if autarkic, and =3 if net seller); $\boldsymbol{X}_{2it}$ is the vector of explanatory variables consisting of the post-harvest farmgate price of maize ($\boldsymbol{p_m}$), proxies for transaction costs and access to markets, and household characteristics; and δ and $\boldsymbol{\gamma}$ are parameters to be estimated. The estimate of interest is the marginal effect of an increase in maize output on maize market position ($E\left[\frac{\partial \Pr(M=3)}{\partial q_{mz}}\right]$).

1.5.4 Step 3

The effect of an increase in maize output on the household's choice of maize marketing channel is estimated using a CRE-Multinomial Logit (MNL) regression.[21] The choice of marketing channel can be represented as:

(6) $Pr(V_{jit} - V_{kit} > 0 \mid q_{mz,it}, \boldsymbol{W}_{it}, c_i, v_t) =$

$$\exp(\lambda_j q_{mz,it} + \boldsymbol{W}_{it}\boldsymbol{\pi_j} + c_i + v_t) \Big/ 1 + \sum_{j=1}^{4} \exp\left(\lambda_j q_{mz,it} + \boldsymbol{W}_{it}\boldsymbol{\pi_j} + c_i + v_t\right)$$

[21] The MNL model, though widely used in studying unordered choice models, suffers with the drawback that it assumes the independence of irrelevant alternatives (IIA). The IIA implies that the odds of choosing one alternative over the other is independent of the characteristics of the other. An alternative to the MNL that relaxes this assumption is the multinomial probit (MNP). However, we prefer MNL over MNP because the choice probabilities of the MNL model are very complicated leading to difficulties in obtaining partial effects on the choice probabilities (which were crucial for our computation of APE of LC on choice of marketing channel) (Hausman and McFadden, 1984; Wooldridge, 2010).

Here V_{jit}- V_{kit} is the difference in utilities obtained from choosing channel *j* vs. channel *k*. $q_{mz,it}$ is as defined above and $\boldsymbol{W}_{it}$ is a vector of control variables consisting of $\boldsymbol{X}_{2it}$ (the same as in Step 2) and residuals from a selection equation described below. λ_j and $\boldsymbol{\pi_j}$ are parameters associated with marketing channel *j*. The estimate of interest is the marginal effect of an increase in maize output on the household's choice of marketing channel ($E\left[\frac{\partial \Pr(V_j - V_k > 0)}{\partial q_{mz}}\right]$).

The CRE-MNL is only estimated using the subset of maize net sellers, which can introduce selection bias if this subset of maize growers is a non-random sub-sample of the full sample of maize-growing households with respect to unobservable, time-varying characteristics. To address this potential problem, we first estimate a CRE-Tobit selection equation for a maize grower's net maize quantity sold using the full sample, where net maize sales are zero for both autarkic and net-buying households. The residuals from this Tobit regression are then used as an additional regressor in the CRE-MNL to test and control for sample selection bias. The use of Tobit instead of probit as a selection equation allows us to solve the selection problem without the need of an exclusion restriction. [22]

[22] Using a probit selection equation without an exclusion restriction could lead to severe collinearity between the generated residuals and explanatory variables. Identification in such a case relies on the nonlinearity of the inverse Mills ratio. By contrast, because the variation in the quantity of maize sold among net sellers is leveraged in the Tobit selection equation, the Tobit residuals have separate variation from the explanatory variables of the main regression (here, CRE-MNL), thus alleviating concerns of multicollinearity and providing a way to control for sample selection bias even in the absence of an exclusion restriction. See Wooldridge (2010) – Procedure 19.3 – for details.

Table 1. 2: Links between values to be estimated/calculated and hypotheses to be tested

Hypothesis	Statement (all refer to maize-growing households)	Values to be estimated/calculated
1	LC households are less likely to become maize net sellers, relative to UC households	$E[(q_{mz}\|LC=1)-(q_{mz}\|LC=0)] *$ $E\left[\frac{\partial \Pr(M \quad =3))}{\partial q_{mz}}\right] < 0$
2	An LC household's probability of being a maize net seller will be less responsive to changes in expected maize prices, relative to a UC household's	$E\left[\frac{\partial q_{mz}}{\partial \boldsymbol{p_e}} \| LC=1\right] * E\left[\frac{\partial \Pr(M \quad =3))}{\partial q_{mz}}\right] <$ $E\left[\frac{\partial q_{mz}}{\partial \boldsymbol{p_e}} \| LC=0\right] * E\left[\frac{\partial \Pr(M \quad =3))}{\partial q_{mz}}\right]$
3	Net seller LC households are less likely than UC households to sell to the FRA	$E[(q_{mz}\|LC=1)-(q_{mz}\|LC=0)] *$ $E\left[\frac{\partial \Pr(V_{FRA}-V_k>0)}{\partial q_{mz}}\right] < 0$

1.5.5 Test of Hypothesis

The estimates from Step 1 and Step 2 are multiplied as shown in Table 1.2 to test hypotheses 1 and 2. Similarly, the product of estimates from Step 1 and Step 3 are used to test hypothesis 3. Standard errors are computed by bootstrapping over 500 replications.

1.6 Results

Table 1.3 reports the average partial effects (APEs) from the CRE-POLS switching regressions for maize output by liquidity status for key variables of interest. The residuals in the endogenous switching regression are not statistically significant (at a 10% level of significance). We thus conclude that, controlling for the observables and time invariant unobserved heterogeneity via CRE, liquidity status at planting time is exogenous to maize output. In the subsequent discussion and computations, we focus on the results from the exogenous switching regression only and interpret our results as associations.

Table 1. 3: Average Partial Effects of Key Variables on Maize Output (kg)

Variables	Exogenous Switching CRE-POLS		Endogenous switching CRE-POLS	
	UC	LC	UC	LC
Household is liquidity constrained=1		-1272.0***		-1389.8
		(70.98)		(2158.7)
Expected farmgate FRA maize price (ZMW/kg, 2017=100)	524.2	123.6	523.5	131.4
	(793.0)	(243.8)	(1552.4)	(405.5)
Expected farmgate maize market price (ZMW/kg, 2017=100)	-38.6	-19.5	-37.8	-27.6
	(211.6)	(63.83)	(359.6)	(102.4)
Residuals			-27.6	313.1
			(3781.4)	(1193.0)
Other controls	Yes		Yes	
Time fixed effects	Yes		Yes	
District fixed effects	Yes		Yes	
CRE time averages	Yes		Yes	
Observations	12,126		12,126	

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors in parentheses have been clustered at HH level and bootstrapped with 500 replications to account for the generated regressor (residuals from the first stage regression of liquidity constraints on all explanatory variables and an instrumental variable).
LC= Liquidity Constrained; UC= Unconstrained; HH=household. ZMW=Zambian Kwacha; FRA= Food Reserve Agency. See Tables 1E.2 and 1E.3 in Appendix E for full results.

We find that liquidity constraints in the production period are associated with a 1,272 kg reduction in maize output (p<0.01), on average. This is approximately equivalent to 1,700 Zambian Kwacha (ZMW) at the FRA's 2014/15 marketing year price (or 280 USD at the exchange rate during that period, or 33% of the annual mean maize production of a Zambian smallholder). However, we find no statistically significant relationship between expected FRA and market prices of maize and household maize output for both LC and UC households. This may in fact be the case, but it is also possible that there is measurement error in our expected maize price variables, which would bias their estimated effects toward zero. The measurement error may arise due to our use of naïve expectations (for tractability) instead of a more sophisticated construct of household price expectations. Secondly, while the use of district level retail prices in lieu of producer prices collected from smallholder maize sellers helps us avoid concerns about incidental truncation, the adjustments for transport costs to convert the district-level retail prices to farmgate prices are rough approximations at best. This adjustment entailed making some potentially strong assumptions about the nature of transport costs (see Appendix C for details). Finally, the variance inflation factor (VIF) for the expected FRA price and the year dummy is greater than 10, signalling a multicollinearity issue.[23] The correlation coefficient between these two variables is also very high (0.90). This is expected because there is relatively little variation in FRA farmgate prices within a given year as the FRA depot-level price is pan-territorial. We therefore interpret with caution the estimated effects of the expected maize prices on maize output.

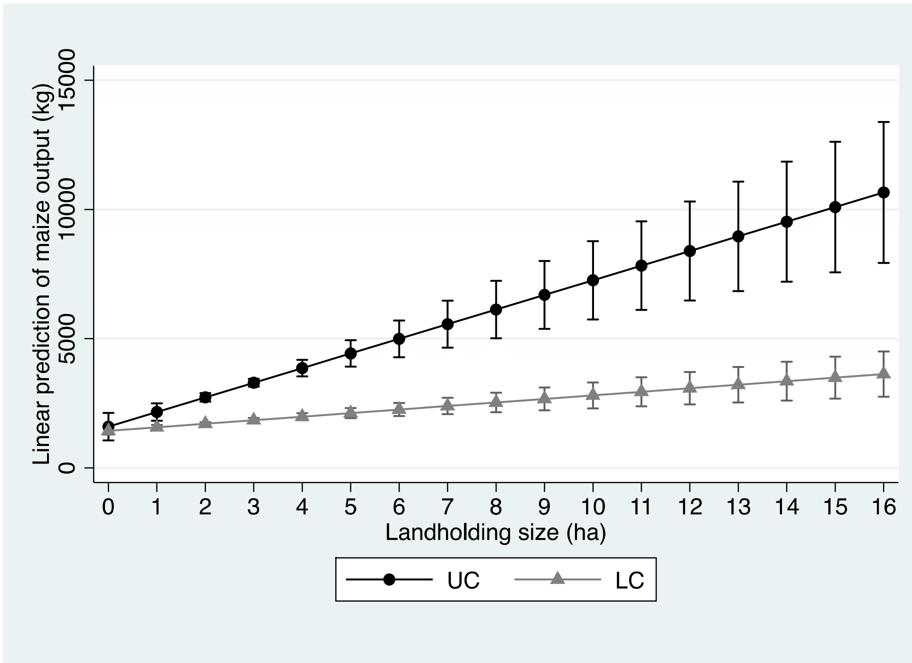
A comparison of APEs of landholding size of LC and UC households reveals that UC households are able to produce, on average, 430 kg more maize from an additional hectare of land as compared to LC households (Table 1E.4 in Appendix E). This is what we would expect if LC households are constrained in their ability to invest in sufficient inorganic fertilizer or improved seed to improve their land productivity. It is also plausible that the effect of liquidity constraints are heterogenous across different landholding categories. This is especially relevant given the recent rise in the prominence of medium scale farmers (i.e., those farming 5+ hectares of land) in Zambia and other relatively land abundant countries in SSA (Jayne et al. 2019). These farmers are found to have better access to credit, land, and other resources as well as political leverage to influence agricultural policy (Ibid.). Figure 2 shows that LC households across all landholding sizes produce less maize output than UC households, and more importantly, the difference in maize output between LC and UC households increases as the landholding size increases. A caveat worth noting here is that almost 90% of LC households in our sample owned 5 hectares or less of land compared to 75% of UC households.

We further use the CRE-POLS switching approach to investigate the premise that the difference in maize output between LC and UC households is at least partly due to LC households' relatively lower capacity to invest in maize productivity-enhancing inputs such as inorganic fertilizer and improved seed.[24] The results of these regressions (Table 1E.5 in Appendix E) suggest that being liquidity constrained is associated with a 113 kg/ha reduction in the rate of fertilizer application to maize and a 19 percentage point reduction in the probability of growing an improved maize variety, on average ($p<0.01$). These numbers represent a 55% and 25% reduction in the fertilizer rate and the probability of using improved seed, respectively, relative to the average fertilizer usage on maize and the average proportion of smallholders using improved seed. This further emphasizes how liquidity constraints are associated with a foregone opportunity for

[23] The VIF for all other variables was within the acceptable range (<=10).
[24] Improved seed refers to both hybrids and improved open pollinated varieties.

households to improve their land productivity through investment in inorganic fertilizer and improved seed.

Figure 1. 2: Predictive margins of liquidity status at planting time across different landholding sizes and with 95% Confidence Interval



Notes: UC: Liquidity unconstrained households; LC: Liquidity constrained households

The key results from the CRE-ordered probit of maize market position are reported in Table 1.4.[25] A one metric ton (1,000 kg) increase in maize output is associated with a 12 percentage point decrease in the probability of being a maize net buyer, and a 14 percentage point increase in the probability of being a net seller ($p<0.01$). Maize market and FRA prices are not statistically significantly related to household maize market position. In addition, we computed the partial effect of an increase in maize output on a household's net maize sales (using a CRE-POLS approach, Table 1E.8, Appendix E) and find that a 1 kg increase in maize output is associated with an average 0.86 kg increase in net maize sales ($p<0.01$).

[25] The CRE-ordered probit failed to converge even though the estimates remain stable after the 15th iteration. We used estimates from 2,000 iterations here. To ensure that results are robust, we repeated the analysis with the value-based definition of maize market position. The model using this definition attains convergence and its results were very similar to the main specification (see Table 1E.7 in Appendix E).

Table 1. 4: Average Partial Effects of Key Variables on the Maize Market Position (CRE-ordered probit)

Variables	Net-buyer	Autarkic	Net-seller
Quantity of maize produced, kg	-0.00012***	-0.000020***	0.00014***
	(0.000016)	(0.0000015)	(0.000016)
Farmgate maize price (ZMW/kg, 2017=100)	-0.0021	-0.00036	0.0025
	(0.012)	(0.0020)	(0.014)
Farmgate FRA maize price (ZMW/kg, 2017=100)	-0.061	-0.010	0.071
	(0.106)	(0.018)	(0.124)
Other controls		Yes	
Time fixed effects		Yes	
District fixed effects		Yes	
CRE time averages		Yes	
Observations		12126	

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level in parentheses
LC= Liquidity Constrained; UC= Unconstrained; HH=household. ZMW=Zambian Kwacha; FRA= Food Reserve Agency. See full results in Table 1E.6 in Appendix E

Table 1.5 summarizes key results of the CRE-MNL for net selling households' choice of maize marketing channel for their largest maize transaction. An additional kilogram of maize produced does not have any statistically significant association with choosing to sell to small scale traders. However, a one metric ton increase in maize produced is associated with a 4 percentage point increase in the probability of selling to the FRA, a 1.2 percentage point increase in the probability of selling to a large-scale trader, and a 5.4 percentage point decrease in the probability of selling to another households ($p<0.01$). These results support our proposition that households that produce a larger maize surplus would be more likely to sell to marketing channels that entail larger fixed costs (such as uncertainty and payment delays associated with selling to the FRA, negotiation and search costs for large scale sellers, and transport for both).

The estimates computed above are used to test the hypotheses stated in Table 1.2, and the results are summarised in Table 1.6. In support of hypothesis 1, LC households are found to be 18 percentage points less likely to be net sellers of maize ($p<0.05$). With respect to hypothesis 2, we do not find evidence for either LC or UC households that expected maize prices have a statistically significant effect on households' probability of being net sellers. However, as discussed earlier, due to caveats about measurement error in expected prices, we are unable to draw a firm conclusion regarding hypothesis 2. Lastly, consistent with hypothesis 3, being liquidity constrained is found to be associated with a 5 percentage point reduction in the probability of selling to the FRA. LC households are also found to be 2 percentage points less likely to sell to large scale traders but 7 percentage points more likely to sell to other households (p<0.05). There is no statistically significant relationship between being liquidity constrained and selling to small scale traders.

Table 1. 5: Average Partial Effects of Maize Output on Choice of Marketing Channel made for the Largest Transaction of Maize by Net Seller Households (CRE-Multinomial Logit)

Variables	Average Partial Effects			
	Small scale traders	FRA	Large scale traders	Other households
Quantity of maize produced, kg	0.0000030 (0.0000081)	0.000039*** (0.0000089)	0.000012*** (0.0000036)	-0.000054*** (0.000013)
Residuals from CRE-Tobit selection equation§	Yes			
Time fixed effects	Yes			
Province fixed effects#	Yes			
CRE time averages	Yes			
Observations	7108			

Notes: *** p<0.01, ** p<0.05, * p<0.1; standard errors are clustered at household level and bootstrapped with 500 replications to account for the generated regressor (CRE-Tobit residuals). §The CRE-Tobit residuals are significant at 1% level of significance, implying that the sample of net sellers is non-random, and our estimates would have been biased if we had not corrected them through inclusion of the residuals; #Province fixed effects are used in place of district fixed effects because the model fails to converge when using the latter. (See Tables 1E.9 and 1E.10 in Appendix E for the first-stage CRE-Tobit results for the quantity of maize sold and the full CRE-MNL results, respectively.)

Finally, to alleviate concerns about the hypothetical bias in the definition of liquidity status, we re-conduct the analysis using the alternate definition of liquidity (criteria 2 only). Results from the analysis are presented in Tables 1E.11 and 1E.12 in Appendix E. We find that LC households produce, on average, 1,562 kg less maize as compared to UC households, and thus are 22 percentage points less likely to be net sellers of maize (p<0.01). In addition, net selling LC households are 6 percentage points less likely to sell to the FRA (p<0.01). These findings are consistent with those obtained from the main specification.

1.7 Robustness checks

We now discuss some of the limitations of this study and the additional analyses conducted (wherever possible) to address them.

Table 1. 6: Test of Hypotheses

Hypothesis	Effect of interest	APE
1	Liquidity constraint on the probability of being a net buyer	0.15** (0.077)
	Liquidity constraint on the probability of being a net seller	-0.18** (0.088)
2	Expected FRA price on probability of being a net seller for LC HH	0.017 (0.051)
	Expected FRA price on probability of being a net seller for UC HH	-0.003 (0.013)
	Market price on probability of being a net seller for LC HH	0.074 (0.169)
	Market price on probability of being a net seller for UC HH	-0.005 (0.031)
3	Liquidity constraint on the probability of selling to a small-scale trader	-0.004 (0.007)
	Liquidity constraint on the probability of selling to FRA	-0.049** (0.024)
	Liquidity constraint on the probability of selling to a large-scale trader	-0.015** (0.007)
	Liquidity constraint on the probability of selling to other households	0.068** (0.031)

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors in parentheses are based on 500 bootstrap replications
APE= Average partial Effect; LC= Liquidity Constrained; UC= Unconstrained; HH=Household; FRA= Food Reserve Agency

1.7.1 Validity of the instrument variable

The lagged moisture shock variable we use as an instrument may not be valid if there are channels by which it can influence maize output apart from its effect on current liquidity constraint status. For example, a moisture shock in period t-1 could affect maize output through a change in soil quality that persists into period t. We do not have a way to test this but do not expect this be a serious concern, as a substantial and persistent change in soil quality is only likely if the dry spell is very severe. In such a case, soil nitrogen becomes unavailable to the plant in t-1 and leads to a carry-over of this nitrogen into the next season, which would *increase* the maize yield in period t (S. Snapp, personal communication, April 2, 2020). Thus, in the rare case that the instrument affects the maize output through a change in soil quality, our estimates of the impact of liquidity would be biased upwards (less negative effect of LC) and can still be considered as a conservative lower limit (in absolute value) to the true effect.

A second concern is related to potential serial correlation in the moisture shock variables. If some geographical locations are more prone to experiencing dry spells over several years, a moisture shock in period t-1 could also be correlated with weather conditions in such locations in period t, and thus to maize output. We alleviate some of this concern by including a measure of long term average growing season moisture shocks and rainfall as controls in our models. Our use of CRE to control for time-constant unobserved heterogeneity should also alleviate some of these concerns. In addition, we run a falsification test by including a lead of the moisture shock variable (i.e., the moisture shock in period t+1) in the first stage CRE-POLS for liquidity status and the CRE-switching POLS for maize output. We test the null hypotheses that maize output and liquidity status are not correlated with moisture shocks in the next time period through any serial correlation in the moisture shock variable. We fail to reject this null for both liquidity status and maize output, which further supports the validity of the instrument (full results in Table 1E.13 in Appendix E).

1.7.2 Two-stage least squares as an alternative to switching regression

To further test the robustness of our results, we also re-analyze the maize output equation using a CRE-two stage least squares (2SLS) approach as an alternative to the endogenous switching CRE-POLS of maize output. Unfortunately, we are unable to generate the effect of expected maize prices for LC and UC households separately due to lack of sufficiently strong IVs of the interaction terms of liquidity status and expected prices. The results (recorded in Table 1E.14 in Appendix E) show that LC households produce 2,698 kg less maize, on average, than UC households ($p<0.1$). The test of endogeneity of liquidity status in the 2SLS estimation fails to reject the null of exogeneity. Both these results are consistent with our main results.

1.7.3 Sensitivity analysis using different measures of maize market prices

We use two alternative measures of market prices of maize to investigate whether our results are sensitive to the measure of maize market price used in the main analysis, which is based on the retail maize market price in August of the prior (current) agricultural marketing season for the expected (realized) market price. The first alternative measure is the average of monthly maize retail prices over the entire peak maize marketing season (May-October). The second is a similar measure computed for the months of July, August, and September only. However, using these alternative measures of prices does not change the analysis in any significant manner. (Full results are in Tables 1E.15 and 1E.16, Appendix E.) Both maize output and maize market position remain unresponsive to both expected and realized maize prices.

1.8 Conclusions and policy implications

In this article we study the effect of liquidity constraints during the production period on maize market participation among maize-growing smallholder households in Zambia. We show empirically that, compared to liquidity unconstrained households, liquidity constrained households are not able to invest as much in maize productivity-enhancing inputs (e.g., inorganic fertilizer and improved maize seed) and produce less maize output. This, in turn, reduces their probability of being a maize net seller. These results complement those of Alene et al. (2007), Boughton et al. (2007), and Mather et al. (2013), which found that insufficient access to public and private assets can limit a smallholder household from producing a marketable surplus and thus reduce their participation in output markets. They support the finding by Kusunose et al. (2020) that liquidity constrained smallholder farmers in rural Zambia cut back on use of productive agricultural resources to cope with poor harvests. They are also consistent with Fink, Jack, and Masiye (2020), who show that a small credit intervention in the lean season in rural Zambia leads to significant improvements in agricultural production by releasing family labor from non-farm piecework and enabling them to devote more time to on-farm work.

We hypothesized but did not find evidence that maize output of liquidity constrained households is less responsive to an increase in expected maize prices relative to unconstrained households. We suspect measurement error in the price variables and issues of multicollinearity could be partially responsible for this result. Finally, we find evidence that liquidity constraints during the production period are associated with the marketing channel chosen by the household for its largest maize sale. Since liquidity constrained households produce less maize (and likely have a smaller marketable surplus), they are less likely to overcome the high fixed costs associated with accessing some channels. Specifically, in the case of maize markets in Zambia, liquidity constrained net seller households were found to be less likely to sell to the parastatal marketing board, FRA, as compared to small scale traders and other households. Overall, our results show that production bottlenecks, such as liquidity constraints during the production period, can limit a household's capacity to benefit from remunerative market and price policies.

These results support the view that price policies may have limited effects on smallholders' food production and marketing responses if they lack access to the productive assets and inputs needed to expand production (Barrett 2008). This can exacerbate the disproportionate capture of benefits from agricultural market policies by wealthier farmers, as has indeed been reported for

Zambia (Jayne et al. 2011; Mason and Myers 2013; Fung et al. 2020). The results also have implications for a relatively land abundant country like Zambia where much of the increase in maize production has been a result of increases in maize acreage and not increases in maize productivity (Burke et al. 2010). In recent years, the FRA has reduced its maize purchases and shifted more expenditure and attention towards provision of food relief to vulnerable populations, due largely to budget constraints. There has also been evidence of better participation by private sector players in Zambian maize output markets (Mulenga et al. 2019). This is a welcome shift in light of the results of this article and the recent threat to household food security in Zambia due to droughts in both the 2017/18 and 2018/19 agricultural seasons. Though one of the main goals of the FRA is to improve farmer incomes, this study's findings demonstrate that the presence of liquidity constraints during the planting period contributes significantly toward constraining the maize output of many smallholder maize growers such that they are not able to produce a surplus, which in turn hinders their ability to enjoy some of the benefits of the FRA's maize purchase program.

APPENDICES

APPENDIX 1A: Additional steps of conceptual model

Let a potentially risk-averse agricultural household maximize its expected utility of consumption of maize (c_{mz}), leisure (c_l), and market-purchased goods ($\boldsymbol{c_{mk}}$), given household level characteristics ($\boldsymbol{z^h}$) that affect consumption tastes and preferences (equation 1a), subject to several constraints (equations 1b to 1e, described below). For simplicity, we assume maize to be the only agricultural product produced by the household. We explicitly model liquidity constraints during the production period and assume that the liquidity constraints apply only to the variable production inputs (here: labor (l) and non-labor variable inputs ($\boldsymbol{x}$)).

The household's problem is summarized below:

$$\max_{c_{mz},\ c_l,\ \boldsymbol{c_{mk}},\ q_{mz}, \boldsymbol{x},\ l} \quad EU(c_{mz}, c_l, \boldsymbol{c_{mk}};\ \boldsymbol{z^h}) \qquad \text{(1a)}$$

$$q_{mz} = g(l, \boldsymbol{x};\ \boldsymbol{z^q}\ ) + \varepsilon \qquad \text{(1b) [Production function]}$$

$$q_{mz} - c_{mz} = m \qquad \text{(1c) [Equilibrium condition]}$$

$$\eta(\boldsymbol{p_x x} + wl - K) = 0 \qquad \text{(1d) [Liquidity constraint]}$$

If LC: $(\boldsymbol{p_x x} + wl - K) = 0\ and\ \eta > 0$

If UC: $(\boldsymbol{p_x x} + wl - K) < 0\ and\ \eta = 0$

$$\boldsymbol{p_{mk} c_{mk}} + wl + \boldsymbol{p_x x} \leq p_e m + w(T - c_l) \qquad \text{(1e) [Income constraint]}$$

The production function (1b) represents the production technology that transforms farm labor (l) (consisting of hired and/or family labor) and non-labor inputs ($\boldsymbol{x}$) into maize (q_{mz}), given the levels of fixed and quasi-fixed factors affecting production ($\boldsymbol{z^q}$) and random shocks (ε) such as weather that can shift output supply. The equilibrium constraint (1c) indicates that the quantity of maize sold (m) is the quantity of maize produced minus the quantity of maize consumed. If m is negative, it implies that the household purchased additional maize beyond its production to meet consumption needs. Let w and $\boldsymbol{p_x}$ denote the prices of labor (l) and non-labor inputs ($\boldsymbol{x}$), respectively, assumed to be known at planting time. Following de Janvry et al. (1992), the input purchase liquidity constraint (1d) states that if a household is liquidity constrained (LC), liquidity is binding (with shadow price of liquidity $\eta > 0$) and the amount of agricultural inputs used will be limited by some upper limit K that represents the household's available cash. On the other hand, if the household is not liquidity constrained (UC), $\eta = 0$ and use of inputs is not limited by K. Finally, the income constraint (1e) balances the income and expenditures of the household. Here p_e is the household's expectation, as of planting time, of the maize price that will prevail at harvest time; T is the household's total time endowment; and $\boldsymbol{p_{mk}}$ is the vector of prices for other market purchased consumption goods. Combining the income and liquidity constraints (1e and 1d, respectively) gives us the full income constraint as follows:

$$\boldsymbol{p_{mk} c_{mk}} + wl + \boldsymbol{p_x x} + \eta(\boldsymbol{p_x x} + wl - K) \leq p_e m + w(T - c_l) \quad \text{(1f) [Full-income constraint]}$$

If LC, $\eta > 0$ and $\boldsymbol{p_{mk} c_{mk}} + wl\ (1 + \eta) + \boldsymbol{p_x x}(1 + \eta) \leq p_e m + w(T - c_l) + \eta K \qquad \text{(2a)}$

where $1 + \eta$ represents an implicit input price markup for households that are liquidity constrained.

If UC, $\eta = 0$ and $\boldsymbol{p_{mk}}\boldsymbol{c_{mk}} + wl + \boldsymbol{p_x}\boldsymbol{x} \leq p_e m + w(T - c_l)$ (2b)

Liquidity-constrained and unconstrained households will then maximize their expected utility under different sets of constraints, and thus have different input demand and output supply functions:

If LC: $\boldsymbol{q}^{\boldsymbol{LC}} = \boldsymbol{q}^{\boldsymbol{LC}}(p_e, \boldsymbol{p_{mk}}, w(1 + \eta), p_x(1 + \eta), K, \boldsymbol{z}^{\boldsymbol{h}}, \boldsymbol{z}^{\boldsymbol{q}})$ (3a)

If UC: $\boldsymbol{q}^{\boldsymbol{UC}} = \boldsymbol{q}^{\boldsymbol{UC}}(p_e, \boldsymbol{p_{mk}}, w, p_x, \boldsymbol{z}^{\boldsymbol{h}}, \boldsymbol{z}^{\boldsymbol{q}})$ (3b)

where $\boldsymbol{q}^{\boldsymbol{LC}}$ and $\boldsymbol{q}^{\boldsymbol{UC}}$ denote the vector of input demand and output supply functions for LC and UC households, respectively.

APPENDIX 1B: Test for Attrition bias

We follow recommendations made by Wooldridge (2010) to check for attrition bias. To do this we first compute a dummy variable (s_{it+1}) that takes the value of 1 if a household was part of the balanced sample used for analysis, and 0 otherwise. This means that s_{it+1} takes value the 0 if a maize growing household interviewed in RALS 2012 dropped out of the analytical sample either due to (i) not being successfully re-interviewed in RALS 2015, or (ii) not cultivating maize in the agricultural year captured by RALS 2015. Then, using the sub-sample of the first wave of the survey only (RALS 2012), we re-estimate each regression equation in the article including s_{it+1} as an additional regressor.

The test of attrition bias consists of testing the null hypothesis that the parameter on the dummy variable s_{it+1} equals zero against a two-sided alternative that it does not equal zero, conditional on all observed covariates. In general, this regression-based test of attrition bias is implemented using data from all but the last wave of a given panel survey. Because we use two waves of household survey data, that means that our implementation of this test can use only one survey wave of data -- the first one. This implies that in our attrition bias test for each regression, we cannot include household fixed effects and thus are not able to control for time-invariant unobserved heterogeneity.

Our approach is slightly different than that proposed by Wooldridge (2010) because we compute s_{it+1} based on attrition due to re-interview *and* maize growing status, whereas Wooldridge (2010) uses the test only for attrition based on re-interview. To test for attrition bias due to maize growing status, we could use a selection equation for maize growing households. However, to conduct this test successfully, we would need an exclusion restriction that is statistically significantly related to maize growing status but not to unobservables affecting any of the dependent variables in our analysis. Unfortunately, we are unable to find such exclusion restriction variables. However, we believe that attrition due to maize growing status should not be a cause of concern since the main reason for attrition in our case was the lack of a successful re-interview, not maize growing status. Among the first-wave maize growing households that were not re-interviewed in the second wave (1,711), only 22% (389) left the sample because they stopped growing maize.

We fail to reject the null of no attrition bias at the 10% level of significance for all regressions except for the ordered probit of maize market position (Table B1). Since we control for household level unobserved heterogeneity in our main regressions, in addition to a wide range of observed covariates, we believe that there is no major cause for concern for attrition bias in our main results.

Table 1B. 1: Test results for attrition bias

Outcome variable		p-value
HH is liquidity constrained at planting time=1		0.388
Maize output (kg)	For liquidity constrained households	0.607
	For unconstrained households	0.532
Quantity based maize market position		0.000***
Value based maize market position		0.000***
Net maize sales (kg)		0.860
Total maize sales (kg)		0.285
Maize marketing channel		0.367

Notes: The reported p-values have been obtained from OLS of given outcome variables against all observed covariates used in main regression and for all maize growing households of 2012 wave. N= 7,774 for all regressions except for maize marketing channel. N= 4,632 for maize marketing channel.
***p < 0.01, **p < 0.05, *p < 0.10

APPENDIX 1C: Computation of expected and realized farmgate FRA and market price of maize

We chose not to use household level prices recorded by RALS in the analysis for the following reasons:
1) Prices in the RALS are only collected for households that sell maize (which comprise of 42% of the sample), thus generating concerns about incidental truncation if we use these prices.
2) Household-level prices are used to compute one of our main outcome variables, maize market position. Using the same prices as an explanatory variable could easily result in simultaneity bias.

The following constructs of prices are used instead:

1) ***Realized farmgate market price of maize:***
We have access to data on monthly district level retail maize prices for Zambia. These prices were observed in the nearest district administrative town. We use these prices as estimates of the maize purchase price offered by private traders to smallholder farmers within a given village. Prices observed in the month of August of the relevant marketing period are used for the main analysis because that is when most maize sales have been observed in Zambia across different years and provinces. Alternatively, an average of retail market prices covering several months were also used to conduct sensitivity analysis (Section 6.4 in main text).

A major limitation with using district-level retail maize prices for the purposes of this paper is that because such prices do not account for the cost of transporting maize from the village to the town, they do not represent farmgate prices, which are more representative of the prices actually faced by the household. Fortunately, for farmers whose largest maize sale was made somewhere away from their homestead, RALS records their transport costs (per kilogram per kilometer) to that point of sale. Additionally, RALS also records an approximate measure of the cost of transporting maize to the nearest FRA depot for all households, irrespective of whether or not they sold any maize to FRA.
Using this information, we are able to construct a piecewise transport cost of maize for each cluster in each year. It is expected (and observed in the data) that the cost of transport per unit per kilometer falls as the distance of sale increases. This is expected because: i) The most expensive component of transporting maize from a typical Zambian village to the nearest district-level administrative town is the transport cost (per kg per km) from the village to the nearest feeder road; ii) likewise, transport costs (per kg, per km) on a feeder road are more expensive than transport on a tarmac road; and iii) there may be fixed costs of transporting maize, such as a fixed payment made in contracting the transport to a middleman. This fixed cost then translates into lower costs per kilometer as the distance travelled from a homestead to the nearest district-level administrative town increases. Following Mason et al. (2015), we compute a piecewise maize transport cost per kilogram per kilometer for the following travel distance categories: 0-5 km, 5-10 km, and more than 10 km. These categories are appropriate because: (i) most households in rural Zambia are 0-5 km from a feeder road, (ii) the district administrative town is often located 10 km or further away from households; and (iii) these categories provide a sufficient number of observations in each category to compute a village (cluster) level median transport cost per kilogram per kilometer. The rule of thumb used in computing this median was

to only compute one at the village (cluster) level if the cluster contained five or more observations of transport costs.. When this condition was not met, then if there were five of more observations at the that level. district level, we computed a district-level median. If that also was not feasible, we computed a provincial-level median. The piecewise transport cost (per kg, per km) assigned to each household was then the median available for households in that village, be it a village-, district-, or provincial-median. This piecewise transport cost (per kilogram, per kilometer) was then used to compute an estimate of the maize transport costs (per kilogram) from each household's homestead to the nearest district town. We then computed the farmgate market price of maize by subtracting this transport cost from the district mean retail maize price.

2) Expected farmgate price of maize:
We assume that a household's expected farmgate (market) price of maize is represented by a simple naïve expectation of the realized farmgate maize price, computed as described in (1) above. Thus, in practice, the expected farmgate (market) price of maize in period (marketing season) t is the realized farmgate maize price observed in period t-1; the marketing season in the year prior. RALS records maize transport costs for period t (the current marketing season) but not for period t-1. We thus use maize transport costs observed in period t-1 to compute those in period t (the next year), which assumes that maize transport costs do not change significantly between two consequent marketing seasons.

3) Expected and realized farmgate FRA price:
FRA maize purchase prices are pan-territorial and announced by the government around June-July of every marketing year. As with farmgate prices, we assume that the expected FRA price in any marketing period t is a naïve price expectation. We thus assume that the expected FRA price in period t is the FRA's publicly announced pan-territorial price as of the marketing season prior to the marketing season of interest to us (i.e., the FRA price as of the planting time). The FRA price as of marketing season was the price announced at the time the smallholders actually sold maize.
In practice, the nearest FRA depot for most smallholder maize farmers in RALS is not in the farmer's village, and the distance between a farmer's homestead and the nearest depot various considerably across the sample. In addition, farmers incur costs to transport maize from their homestead to the nearest FRA depot, which RALS records for both the planting and marketing periods. This implies that household-specific transport costs to the nearest depot are heterogenous, which in turn means that once deduct a household's transport costs to the nearest depot, the FRA purchase price that farmers face is heterogeneous – not pan-territorial.

All prices and transport costs are adjusted by the consumer price index with a base of 2017.

APPENDIX 1D: Summary Statistics

Table 1D. 1: Summary statistics for explanatory and dependent variables used in the analysis (by RALS wave)

	2012		2015	
	Mean	**SD**	**Mean**	**SD**
Panel A: Explanatory variables				
Expected farmgate FRA price (ZMW/kg, 2017=100)	2.21	0.11	1.79	0.10
Expected farmgate market maize price (ZMW/kg, 2017=100)	1.26	0.35	1.60	0.48
Farmgate FRA maize price (ZMW/kg, 2017=100)	2.04	0.07	1.88	0.07
Farmgate maize price (ZMW/kg, 2017=100)	1.41	0.58	1.71	0.41
Commercial basal fertilizer price (district median, ZMW/kg, 2017=100)	6.13	1.16	5.66	0.71
Wage to weed 0.25 ha (district median, ZMW, 2017=100)	99.7	40.2	92.7	37.5
Maize seed price (district median, ZMW/kg, 2017=100)	9.24	6.11	10.42	5.09
Age of the HH head (years)	46.4	14.6	49.1	14.5
Education of household head (years)	6.15	3.66	6.06	3.67
Male-headed household=1	0.82	0.38	0.80	0.40
Full-time adult equivalents	5.01	2.26	5.19	2.28
Landholding size (ha)	3.15	3.21	3.29	3.40
Tropical livestock units	2.83	8.10	2.80	7.66
Number of plows	0.42	0.86	0.50	0.94
Number of harrows	0.07	0.29	0.08	0.31
Number of ox-carts	0.15	0.40	0.18	0.43
Distance to feeder road (cluster median, km)	0.94	2.95	1.01	2.40
Distance to tarmac road (cluster median, km)	28.3	35.0	24.9	30.5
Distance to agricultural market (cluster median, km)	23.4	24.6	23.1	23.8
Number of maize traders visiting village between May-October	3.71	3.14	3.58	2.59
HH owned a radio at the beginning of marketing period	0.66	0.47	0.64	0.48
HH owned a cellphone at the beginning of marketing period	0.58	0.49	0.65	0.48
HH owned a bicycle at the beginning of marketing period	0.70	0.46	0.70	0.46
HH experienced moisture shock in current growing season(t)=1	0.18	0.38	0.48	0.50
Growing season rainfall (mm)	788.4	81.5	833.9	74.9
HH has experienced long term moisture shock (16-yr MA) =1	0.57	0.49	0.41	0.49
Long run mean growing season rainfall (mm) (16-yr MA)	797.1	63.7	806.9	68.0
HH experienced moisture shock in last growing season (t-1) (Instrument)=1	1.00	0.05	0.42	0.49

Table 1D.1 (cont'd)

Panel B: Dependent variables					
Quantity of maize produced by HH (kg)		3777	6667	3835	6710
Quantity of inorganic fertilizer used on maize crop by HH (kg/ha)		192	214	217	185
HH used improved maize seed =1		0.62	0.49	0.69	0.46
Net maize sales made by the HH (kg)		2282	5793	2390	6229
HH maize market position, No. (%)	Net seller	3,647 (60.2)		2,844 (46.9)	
	Autarkic	1,292 (21.3)		1,270 (21.1)	
	Net buyer	1,124 (18.5)		1,941 (32.0)	
No. of observations		6063		6063	
Choice of maize marketing channel among the net-sellers, No. (%)	FRA	2525 (69.2)		617 (21.7)	
	Small scale traders	509 (14.0)		1530 (53.8)	
	Large scale traders	300 (8.2)		456 (16.0)	
	Other HH	313 (8.9)		241 (8.5)	

Notes: HH=household; MA=moving average; ZMW=Zambian Kwacha

Table 1D. 2: Response to the question: What is the most important reason a household did not purchase commercial fertilizer?

	2012		**2015**		**Total**	
	Number	*%*	*Number*	*%*	*Number*	*%*
Did not have enough cash	3,141	78.5	2,520	82.3	5,661	80.2
It was not profitable to buy fertilizer	390	9.8	118	3.9	508	7.2
Transport costs were too high	38	1.0	29	1.0	67	0.9
Fertilizer was not available in stores	77	1.9	29	1.0	106	1.5
Soil is fertile, don't need fertilizer	267	6.7	149	4.9	416	5.9
Had enough fertilizer	71	1.8	211	6.9	282	4.0
Others	15	0.4	8	0.3	23	0.3
Total	3,999	100.0	3,064	100.0	7,063	100.0

Table 1D. 3: Response to the question: Why did the household not receive FISP fertilizer?

	2012		**2015**		**Total**	
	Num ber	*%*	*Num ber*	*%*	*Num ber*	*%*
Could not afford FISP down payment	980	29.8	760	24.3	1740	27.1
Could not afford cooperative membership	553	16.8	420	13.4	973	15.1
Not eligible for FISP	371	11.3	723	23.1	1094	17.0
FISP fertilizer not available	407	12.4	233	7.4	640	10.0
Did not want to get FISP because of late delivery/other reasons	276	8.4	388	12.4	664	10.3
Denied cooperative membership/Did not want membership	306	9.3	273	8.7	579	9.0
Soil is fertile (do not need fertilizer)	232	7.1	132	4.2	364	5.7
Don't know	101	3.1	50	1.6	151	2.4
Others	63	1.9	155	4.9	218	3.4
Total	3289	100.0	3134	100.0	6423	100.0

Table 1D. 4: Difference in means of key variable between the LC and UC households (LC-UC)

Variables	**Criteria 1 or 2**	**Criterion 1**	**Criterion 2**
Landholding size (ha)	-1.05***	-0.89***	-0.94***
Full-time adult equivalents	-0.60***	-0.47***	-0.73***
Tropical livestock units	-1.49***	-1.25***	-1.30***
Number of plows	-0.24***	-0.20***	-0.19***
Number of harrows	-0.07***	-0.06***	-0.05***
Number of oxcarts	-0.11***	-0.09***	-0.08***
HH owned a bicycle at the beginning of the marketing period = 1	-0.19***	-0.17***	-0.19***
HH owned a radio at the beginning of the marketing period = 1	-0.19***	-0.18***	-0.20***
HH owned a cell phone at the beginning of the marketing period = 1	-0.24***	-0.21***	-0.26***
HH owned a television at the beginning of the marketing period = 1	-0.19***	-0.17***	-0.17***
Gross per capita income, ZMW	-1,823***	-1,593***	-1,587***
Non-farm income earned during peak maize marketing season, ZMW[#]	-4,065***	-3,547***	-3,240***
Distance to feeder road (cluster median, km)	-0.06	-0.1	-0.05
Distance to tarmac road (cluster median, km)	5.46***	6.24***	4.39***
Distance to district town (cluster median, km)	2.75***	3.01***	2.64***
Distance to agricultural market (cluster median, km)	3.08***	3.60***	1.45**
No. of maize traders visiting village during peak maize marketing season[#]	-0.29***	-0.30***	-0.14*
Quantity of fertilizer applied to maize field, kg/ha	-151***	-137***	-225***
HH used improved maize seed=1	-0.32***	-0.28***	-0.52***
Maize productivity (kg/ha)	-783***	-694***	-977***
Amount of maize produced per capita	-394***	-344***	-317***

Notes: [#]Peak maize marketing season runs from May-October. The sample consists of all observations in the analytical sample (N=12126)
*** p<0.01, ** p<0.05, * p<0.1; HH=household; ZMW=Zambian Kwacha

Table 1D. 5: Variation in liquidity status between 2012 and 2015 RALS waves

		RALS 2015	
		UC	**LC**
RALS 2012	**UC**	32%	13%
	LC	23%	33%

Notes: N=6063

Table 1D. 6: Maize market position by RALS wave and liquidity status using quantity-based definition

	Marketing season 2011/12			**Marketing season 2014/15**		
	UC	**LC**	**Total**	**UC**	**LC**	**Total**
Net buyer	17%	26%	23%	17%	31%	24%
Autarkic	16%	31%	26%	16%	31%	24%
Net seller	67%	42%	52%	67%	38%	52%
Sample size	2,698	3,365	6,063	3,290	2,773	6,063

Table 1D. 7: Maize market position by RALS wave and liquidity status using value-based definition

	Marketing year 2011/12			Marketing year 2014/15		
	UC	**LC**	**Total**	**UC**	**LC**	**Total**
Net buyer	16%	26%	22%	29%	39%	34%
Autarkic	15%	30%	25%	16%	31%	24%
Net seller	68%	44%	52%	56%	31%	42%
Sample size	2,698	3,365	6,063	3,290	2,773	6,063

Table 1D. 8: Choice of marketing channel for the largest maize transaction made by net sellers, by RALS wave and liquidity status

	Marketing year 2011/12			**Marketing year 2014/15**		
	UC	**LC**	**Total**	**UC**	**LC**	**Total**
Small scale trader	12%	21%	17%	24%	28%	26%
Large scale trader	10%	9%	10%	17%	14%	16%
FRA	70%	58%	64%	50%	44%	48%
Other households	7%	11%	9%	9%	15%	11%
Sample size	2,002	1,616	3,618	2,343	1,148	3,491

Notes: Other households included sale other households for consumption (96%), schools and hospitals (2%), and NGOs and church (1%).

Table 1D. 9: Descriptive statistics for maize net sellers by maize marketing channel, 2011/12 maize marketing year

	% of net-sellers that sold to channel	**% sold at farmgate**	**Distance covered by those who travelled (km)**			**Farmgate price (ZMW/kg, 2017=100)**		
			Min	**Median**	**Max**	**Min**	**Median**	**Max**
Small scale trader	17	74	.5	7	202	0.58	1.45	11.5
Large scale trader	10	33	.1	10	420	0.58	1.45	11.7
FRA	64	9	.1	5	180	1.49	2.06	2.38
Other households	9	87	0.5	5.5	130	0.64	1.47	4.16
Sample size	3,618	3,618	2,654			3,618		

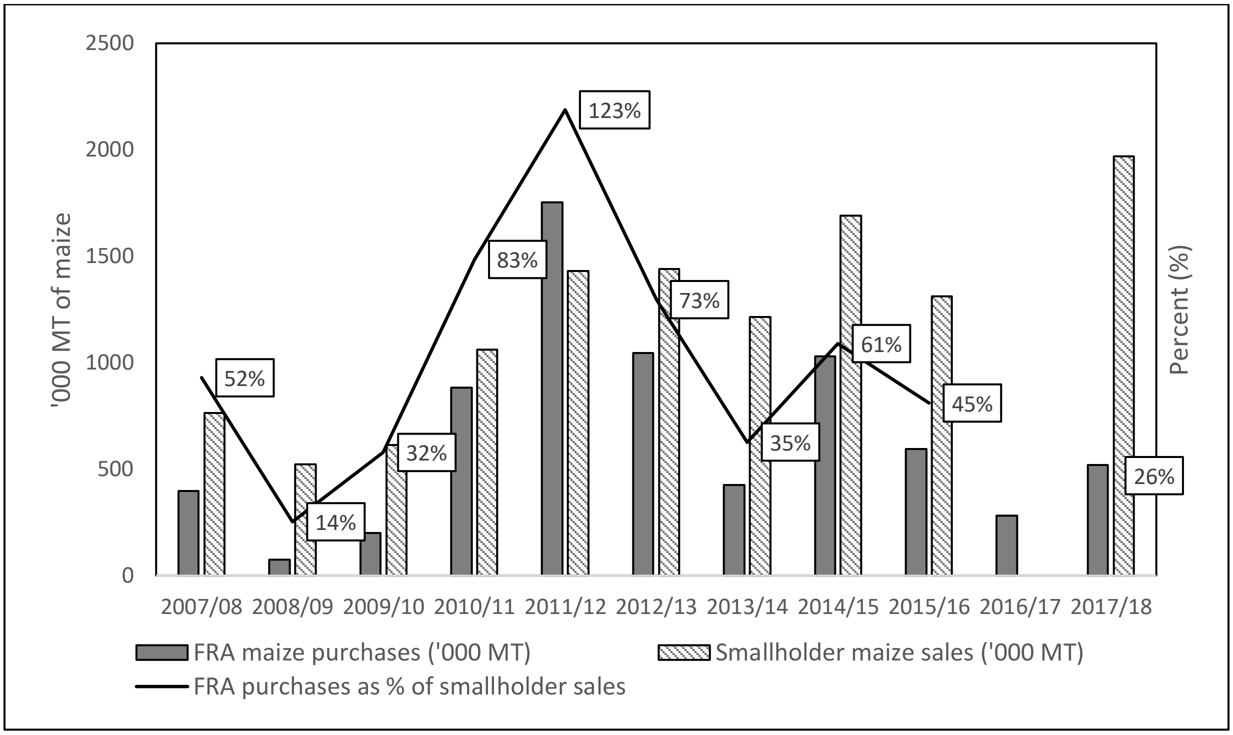
Notes: Farmgate price is the price received by the household at the point of sale and adjusted for the cost incurred in transporting the maize from the homestead to the point of sale. It has been computed using prices and costs reported by the household.

Table 1D. 10: Descriptive statistics for maize net sellers by maize marketing channel, 2014/15 maize marketing year

	% of net-sellers that sold to channel	**% sold at farmgate**	**Distance covered by those who travelled (km)**			**Farmgate price (ZMW/kg, 2017=100)**		
			Min	**Median**	**Max**	**Min**	**Median**	**Max**
Small scale trader	26	66	.15	8	237	0.06	1.40	4.46
Large scale trader	16	30	.1	20	570	0.56	1.40	4.89
FRA	48	11	.15	5	200	0.54	1.74	3.80
Other households	11	85	1	3	60	0.69	1.51	10.7
Sample size	3,618	3,618	2,654			3,618		

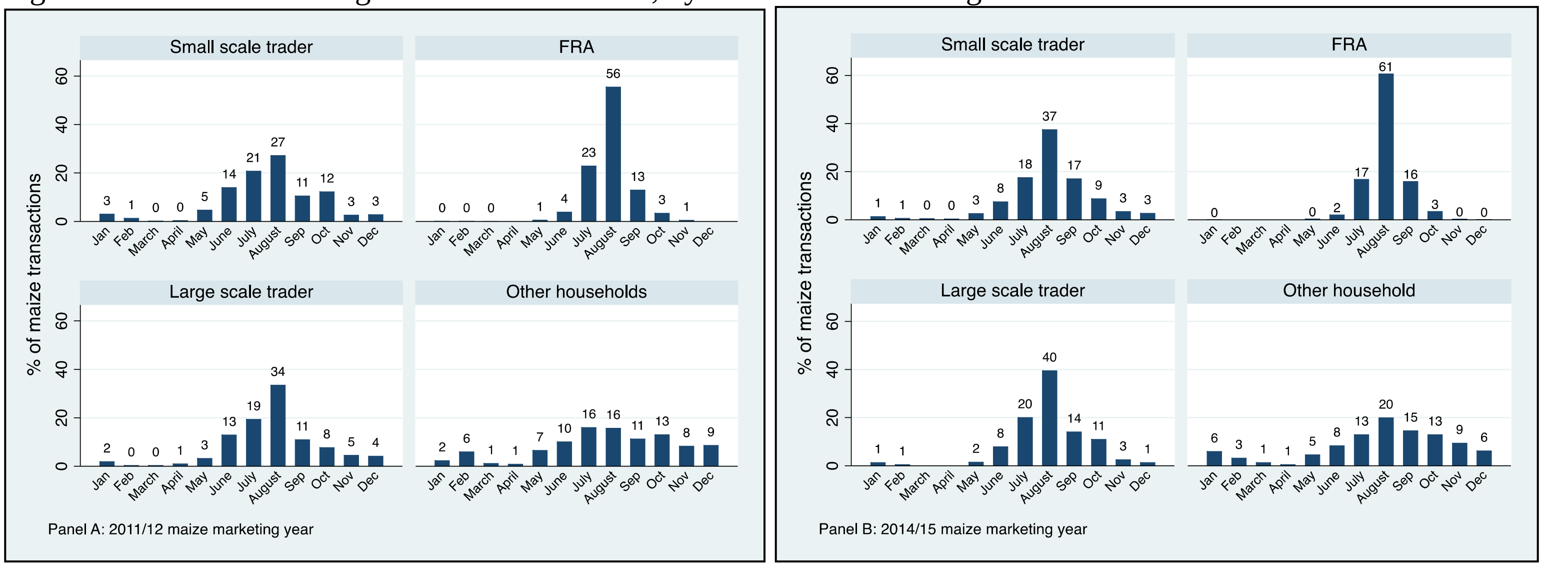
Notes: Farmgate price is the price received by the household at the point of sale and adjusted for the cost incurred in transporting the maize from the homestead to the point of sale. It has been computed using prices and costs reported by the household.

Figure 1D. 1: Trends in FRA maize purchase, smallholder maize sales, and FRA purchase as % of smallholder sales, 2007/08 to 2017/18 marketing years



Source: Mason and Myers (2013) and Fung et al. (2020), compiled data obtained from the FRA, Crop Forecast Surveys, Post-Harvest Surveys, and Supplemental Surveys for relevant years.
Note: Estimates of smallholder maize sales were not available for 2016/17.

Figure 1D. 2: Percent of largest maize transactions, by month and marketing channel



Source: Author’s calculations from RALS 2012 and 2015 survey data.
Note: 2012/12 maize marketing channel in Panel A and 2014/15 maize marketing channel in Panel B

APPENDIX 1E: Full Results

Table 1E. 1**:** First stage regression of liquidity status on full set of exogenous variables: CRE-Linear probability model

Variables	**Coefficient**
Dependent variable: Liquidity status (=1 if HH is LC; = 0 if HH is UC)	
Expected farmgate FRA price (ZMW/kg, 2017=100)	0.027
	(0.0813)
Expected farmgate market maize price (ZMW/kg, 2017=100)	-0.021
	(0.0171)
Commercial basal fertilizer price (district median, ZMW/kg, 2017=100)	-0.021*
	(0.00920)
Wage to weed 0.25 ha (district median, ZMW, 2017=100)	0.00069**
	(0.000226)
Maize seed price (district median, ZMW/kg, 2017=100)	0.00083
	(0.00328)
Age of the HH head (years)	0.0015***
	(0.000398)
Education of household head (years)	-0.017***
	(0.00170)
Male-headed household=1	-0.054***
	(0.0146)
Full-time adult equivalents	-0.00088
	(0.00683)
Landholding size (ha)	-0.0067*
	(0.00289)
Tropical livestock units	-0.0044**
	(0.00150)
Number of plows	-0.028
	(0.0153)
Number of harrows	-0.035
	(0.0414)
Number of ox-carts	-0.044
	(0.0286)
HH experienced moisture shock in current growing season(t)=1	0.0051
	(0.0222)
Growing season rainfall (mm)	0.000087
	(0.000168)
HH has experienced long term moisture shock (16-yr MA) =1	0.0068
	(0.0203)

Table 1E.1 (cont'd)

Long run mean growing season rainfall (mm) (16-yr MA)	-0.00037
	(0.000368)
HH experienced moisture shock in last growing season (t-1) (Instrument)=1	0.092***
	(0.0228)
Time fixed effects	Yes
District fixed effects	Yes
CRE time averages	Yes
Observations	12,126

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level in parentheses; F-stat for instrument (Moisture shock at t-1) = 16.27 (p=0.0001); LC= Liquidity Constrained; UC= Unconstrained; HH=household. ZMW=Zambian Kwacha; MA=moving average

Table 1E. 2: Full results: CRE-exogenous switching POLS for maize output

Variables	**Average Partial Effects**	
	UC	**LC**
HH was liquidity constrained during planting time=1		-1272.0***
		(70.98)
Expected farmgate FRA price (ZMW/kg, 2017=100)	524.2	123.6
	(793.0)	(243.8)
Expected farmgate market maize price (ZMW/kg, 2017=100)	-38.6	-19.5
	(211.6)	(63.83)
Commercial basal fertilizer price (district median, ZMW/kg, 2017=100)	191.8*	-30.3
	(86.26)	(23.56)
Wage to weed 0.25 ha (district median, ZMW, 2017=100)	-3.41	0.017
	(3.762)	(0.912)
Maize seed price (district median, ZMW/kg, 2017=100)	52.9	-23.1
	(40.69)	(14.20)
Age of the HH head (years)	-26.1***	-1.87
	(5.815)	(1.411)
Education of household head (years)	131.4***	55.0***
	(21.85)	(7.500)
Male-headed household=1	-254.8	-106.6*
	(179.7)	(49.61)
Full-time adult equivalents	193.7	42.4
	(109.2)	(36.17)
Landholding size (ha)	566.4***	137.3***
	(103.2)	(32.04)
Tropical livestock units	69.1	37.9**
	(36.72)	(11.65)
Number of plows	180.6	111.9
	(274.6)	(101.4)
Number of harrows	206.2	783.6
	(796.4)	(524.1)
Number of ox-carts	360.7	-0.41
	(500.5)	(247.9)
HH experienced moisture shock in current growing season(t)=1	-2.31	-168.6
	(246.7)	(86.97)
Growing season rainfall (mm)	0.36	-1.11
	(1.751)	(0.641)
HH has experienced long term moisture shock (16-yr MA) =1	192.9	-84.4
	(281.4)	(87.65)

Table 1.E2 (cont'd)

Long run mean growing season rainfall (mm) (16-yr MA)	6.36	2.23
	(6.512)	(1.242)
Time fixed effects	Yes	
District fixed effects	Yes	
CRE time averages	Yes	
Observations	12,126	

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level in parentheses
LC= Liquidity Constrained; UC= Unconstrained; HH=household. ZMW=Zambian Kwacha; MA=moving average

Table 1E. 3**:** Full results: CRE-endogenous switching POLS for maize output

Variables	**Average Partial Effects**	
	UC	**LC**
HH was liquidity constrained during planting time=1		-1389.8
		(2158.7)
Residuals from first stage regression	-27.6	313.1
	(3781.4)	(1193.0)
Expected farmgate FRA price (ZMW/kg, 2017=100)	523.5	131.4
	(1552.4)	(405.5)
Expected farmgate market maize price (ZMW/kg, 2017=100)	-37.8	-27.6
	(359.6)	(102.4)
Commercial basal fertilizer price (district median, ZMW/kg, 2017=100)	192.5	-37.3
	(163.3)	(46.33)
Wage to weed 0.25 ha (district median, ZMW, 2017=100)	-3.43	0.26
	(5.703)	(2.742)
Maize seed price (district median, ZMW/kg, 2017=100)	52.8	-22.9
	(59.92)	(23.21)
Age of the HH head (years)	-26.1***	-1.41
	(9.241)	(2.382)
Education of household head (years)	131.8*	49.7***
	(71.10)	(22.20)
Male-headed household=1	-253.3	-122.8
	(301.3)	(92.09)
Full-time adult equivalents	193.7	42.5
	(153.3)	(49.35)
Landholding size (ha)	566.6***	135.1***
	(161.7)	(46.6)
Tropical livestock units	69.2	36.7*
	(62.7)	(20.0)
Number of plows	181.4	102.8
	(473.6)	(143.0)
Number of harrows	207.2	770.3
	(1549.8)	(753.6)
Number of ox-carts	361.9	-13.5
	(776.6)	(367.3)
HH experienced moisture shock in current growing season(t)=1	-145.43	-175.0
	(397.2)	(143.5)
Growing season rainfall (mm)	0.36	-1.07
	(2.945)	(1.095)
HH has experienced long term moisture shock (16-yr MA)=1	192.8	-81.0

Table 1.E3 (cont'd)

	(281.3)	(88.51)
Long run mean growing season rainfall (mm) (16-yr MA)	6.36	2.27
	(5.545)	(1.394)
Time fixed effects	Yes	
District fixed effects	Yes	
CRE time averages	Yes	
Observations	12,126	

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level in parentheses
LC= Liquidity Constrained; UC= Unconstrained; HH=household. ZMW=Zambian Kwacha; MA=moving average; FRA=Food Reserve Agency

Table 1E. 4**:** Difference in APEs of key variables on maize output between LC and UC households, based on CRE-Exogeneous switching POLS

Variables	**Difference in APE (LC-UC)**
Full-time adult equivalents	-151.3
	(116.4)
Landholding size (ha)	-429.1***
	(115.3)
Tropical livestock units	-31.2
	(38.60)

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level in parentheses
LC= Liquidity Constrained; UC= Unconstrained; APE=Average Partial Effects

Table 1E. 5: Full results: CRE-exogenous switching POLS for inorganic fertilizer and improved seed use in maize

	Dependent variable: Inorganic fertilizer used in maize (kg/ha)		Dependent variable: HH used improved maize seed=1	
	Average Partial Effects		**Average Partial Effects**	
	UC	**LC**	**UC**	**LC**
HH was liquidity constrained during planting time=1		-112.9***		-0.19***
		(4.534)		(0.0110)
Expected farmgate FRA price (ZMW/kg, 2017=100)	22.5	11.4	0.18	0.091
	(75.59)	(33.09)	(0.109)	(0.0960)
Expected farmgate market maize price (ZMW/kg, 2017=100)	-12.3	2.69	-0.0053	0.0048
	(10.53)	(7.660)	(0.0229)	(0.0206)
Commercial basal fertilizer price (district median, ZMW/kg, 2017=100)	9.52	-0.50	-0.0064	0.00083
	(5.093)	(3.890)	(0.0141)	(0.00887)
Wage to weed 0.25 ha (district median, ZMW, 2017=100)	-0.13	-0.12	0.00036	-0.00043
	(0.116)	(0.0915)	(0.000218)	(0.000289)
Maize seed price (district median, ZMW/kg, 2017=100)	0.13	-1.06	0.016***	0.014**
	(2.267)	(1.481)	(0.00464)	(0.00449)
Age of the HH head (years)	-0.081	0.34	-0.000070	-0.000069
	(0.232)	(0.193)	(0.000547)	(0.000497)
Education of household head (years)	6.08***	6.63***	0.014***	0.022***
	(1.043)	(0.844)	(0.00195)	(0.00234)
Male-headed household=1	-12.1	-20.2**	0.060**	-0.042*
	(9.026)	(7.025)	(0.0220)	(0.0184)
Full-time adult equivalents	-4.24	-2.17	-0.0014	0.0076
	(3.463)	(3.606)	(0.00815)	(0.00895)
Landholding size (ha)	-7.45***	-6.01***	0.0039	0.0074
	(1.424)	(1.813)	(0.00281)	(0.00412)

Table 1E.5 (cont'd)

Tropical livestock units	0.33	-0.13	0.0018	0.0047
	(0.796)	(0.866)	(0.00117)	(0.00455)
Number of plows	9.38	11.9	0.021	-0.015
	(6.140)	(8.384)	(0.0139)	(0.0266)
Number of harrows	21.7	-7.62	-0.026	-0.037
	(20.86)	(24.99)	(0.0293)	(0.0805)
Number of ox-carts	-10.6	-6.02	0.021	0.089
	(11.94)	(14.24)	(0.0296)	(0.0489)
HH experienced moisture shock in current growing season(t)=1	-19.0	3.89	-0.040	0.033
	(11.07)	(9.955)	(0.0278)	(0.0288)
Growing season rainfall (mm)	-0.10	0.16	0.000065	0.00057**
	(0.0997)	(0.0913)	(0.000198)	(0.000214)
HH has experienced long term moisture shock (16-yr MA) =1	3.37	-8.88	0.087***	-0.037
	(8.906)	(8.930)	(0.0233)	(0.0260)
Long run mean growing season rainfall (mm) (16-yr MA)	0.043	0.42*	0.00064	0.00095*
	(0.205)	(0.194)	(0.000502)	(0.000464)
Time fixed effects	Yes			
District fixed effects	Yes			
CRE time averages	Yes			
Observations	12,126			

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level in parentheses
LC= Liquidity Constrained; UC= Unconstrained; HH=household. ZMW=Zambian Kwacha; MA=moving average; FRA=Food Reserve Agency

Table 1E. 6: Full results: CRE-ordered probit for quantity-based definition of maize market position

Variables	**Average Partial Effects**		
	Net-buyer	**Autarkic**	**Net-seller**
Quantity of maize produced, kg	-0.00012***	-0.000020***	0.00014***
	(0.0000157)	(0.00000147)	(0.0000161)
Farmgate maize price (ZMW/kg, 2017=100)	-0.0021	-0.00036	0.0025
	(0.0116)	(0.00195)	(0.0135)
Farmgate FRA maize price (ZMW/kg, 2017=100)	-0.061	-0.010	0.071
	(0.106)	(0.0180)	(0.124)
Age of the HH head (years)	0.00021	0.000035	-0.00024
	(0.000229)	(0.0000385)	(0.000267)
Education of household head (years)	0.0017	0.00029	-0.0020
	(0.00114)	(0.000189)	(0.00133)
Full-time adult equivalents	0.021*	0.0038*	-0.025*
	(0.00881)	(0.00180)	(0.0106)
Male-headed household=1	0.013**	0.0021**	-0.015**
	(0.00460)	(0.000826)	(0.00538)
Distance to feeder road (cluster median, km) #	0.0014	0.00024	-0.0017
	(0.00154)	(0.000263)	(0.00180)
Distance to tarmac road (cluster median, km) #	-0.00030	-0.000051	0.00035
	(0.000269)	(0.0000467)	(0.000315)
Distance to agricultural market (cluster median, km) #	0.00021	0.000035	-0.00024
	(0.000338)	(0.0000567)	(0.000395)
Number of maize traders visiting village between May-October #	-0.0018	-0.00030	0.0021
	(0.00207)	(0.000351)	(0.00242)
HH owned a radio at the beginning of marketing period=1	-0.0073	-0.0012	0.0085
	(0.0120)	(0.00205)	(0.0141)
HH owned a cellphone at the beginning of marketing period=1	0.0065	0.0011	-0.0076
	(0.0134)	(0.00221)	(0.0156)

Table 1E.6 (cont'd)

HH owned a bicycle at the beginning of marketing period=1	0.0066	0.0011	-0.0077
	(0.0131)	(0.00222)	(0.0153)
Time fixed effects		Yes	
District fixed effects		Yes	
CRE time averages		Yes	
Observations		12126	

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level in parentheses. HH=household. ZMW=Zambian Kwacha; FRA=Food Reserve Agency. #The cluster level medians were used for these variables even if they were collected at the household level in order to remove outliers. Cluster here refers to the standard enumeration area consisting of approximately 20 villages.

Table 1E. 7: Full results: CRE-ordered probit for value-based definition of maize market position

Variables	**Average partial effects**		
	Net-buyer	**Autarkic**	**Net-seller**
Quantity of maize produced, kg	-0.000080***	-0.0000084***	0.000088***
	(0.00000797)	(0.000000886)	(0.00000839)
Farmgate maize price (ZMW/kg, 2017=100)	-0.024	-0.0025	0.027
	(0.0136)	(0.00145)	(0.0150)
Farmgate FRA maize price (ZMW/kg, 2017=100)	-0.040	-0.0042	0.044
	(0.127)	(0.0134)	(0.141)
Age of the HH head (years)	-0.00045	-0.000047	0.00050
	(0.000257)	(0.0000271)	(0.000284)
Education of household head (years)	0.0024	0.00025	-0.0026
	(0.00126)	(0.000133)	(0.00139)
Full-time adult equivalents	0.018	0.0020	-0.020
	(0.0103)	(0.00130)	(0.0115)
Male-headed household=1	0.012*	0.0013*	-0.013*
	(0.00559)	(0.000596)	(0.00617)
Distance to feeder road (cluster median, km) #	0.00048	0.000051	-0.00053
	(0.00188)	(0.000198)	(0.00208)
Distance to tarmac road (cluster median, km) #	-0.00042	-0.000044	0.00046
	(0.000353)	(0.0000374)	(0.000390)
Distance to agricultural market (cluster median, km) #	0.00012	0.000013	-0.00014
	(0.000388)	(0.0000409)	(0.000429)
Number of maize traders visiting village between May-October #	-0.0069**	-0.00073**	0.0076**
	(0.00249)	(0.000267)	(0.00275)
HH owned a radio at the beginning of marketing period=1	-0.014	-0.0015	0.016
	(0.0138)	(0.00143)	(0.0153)
HH owned a cellphone at the beginning of marketing period=1	-0.0015	-0.00016	0.0017
	(0.0154)	(0.00162)	(0.0170)

Table 1E. 7(cont'd)

HH owned a bicycle at the beginning of marketing period=1	-0.013	-0.0013	0.014
	(0.0151)	(0.00153)	(0.0166)
Time fixed effects		Yes	
District fixed effects		Yes	
CRE time averages		Yes	
Observations		12126	

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level in parentheses. [#]The cluster level medians were used for these variables even if they were collected at the household level in order to remove outliers. Cluster here refers to the standard enumeration area consisting of approximately 20 villages. HH=household. ZMW=Zambian Kwacha; FRA=Food Reserve Agency

Table 1E. 8: Full results: CRE-POLS for net maize sales (maize sold - maize and maize meal purchased)

Variables	Average Partial Effects
Quantity of maize produced, kg	0.86***
	(0.0194)
Farmgate maize price (ZMW/kg, 2017=100)	19.3
	(27.26)
Farmgate FRA maize price (ZMW/kg, 2017=100)	34.6
	(256.2)
Age of the HH head (years)	-4.31***
	(0.691)
Education of household head (years)	-10.9***
	(3.316)
Full-time adult equivalents	-73.2**
	(23.69)
Male-headed household=1	-32.5*
	(13.76)
Distance to feeder road (cluster median, km) #	-6.21
	(4.094)
Distance to tarmac road (cluster median, km) #	0.26
	(0.686)
Distance to agricultural market (cluster median, km) #	-2.63**
	(1.020)
Number of maize traders visiting village between May-October #	-1.33
	(5.199)
HH owned a radio at the beginning of marketing period=1	-41.8
	(31.11)
HH owned a cellphone at the beginning of marketing period=1	-9.17
	(30.48)
HH owned a bicycle at the beginning of marketing period=1	-41.4
	(35.42)
Time fixed effects	Yes
District fixed effects	Yes
CRE time averages	Yes
Observations	12126

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level in parentheses. #The cluster level medians were used for these variables even if they were collected at the household level in order to remove outliers. Cluster here refers to the standard enumeration area consisting of approximately 20 villages. HH=household. ZMW=Zambian Kwacha; FRA=Food Reserve Agency

Table 1E. 9: Full results: CRE-Tobit selection equation of quantity of maize sales made in largest transaction

Variables	Coefficient
Quantity of maize produced, kg	0.74***
	(0.026)
Farmgate maize price (ZMW/kg, 2017=100)	172.0**
	(58.8)
Farmgate FRA maize price (ZMW/kg, 2017=100)	392.2
	(582.0)
Age of the HH head (years)	-4.98***
	(1.33)
Education of household head (years)	7.51
	(5.63)
Full-time adult equivalents	-16.0
	(27.6)
Male-headed household=1	-93.5*
	(45.7)
Distance to feeder road (cluster median, km) #	-23.6
	(12.7)
Distance to tarmac road (cluster median, km) #	1.83
	(1.31)
Distance to agricultural market (cluster median, km) #	-1.53
	(1.64)
Number of maize traders visiting village between May-October #	-2.80
	(9.53)
HH owned a radio at the beginning of marketing period=1	46.6
	(57.9)
HH owned a cellphone at the beginning of marketing period=1	61.1
	(52.5)
HH owned a bicycle at the beginning of marketing period=1	-24.6
	(61.2)
Time fixed effects	Yes
District fixed effects	Yes
CRE time averages	Yes
Observations	12,126

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level in parentheses; #The cluster level medians were used for these variables even if they were collected at the household level in order to remove outliers. Cluster here refers to the standard enumeration area consisting of approximately 20 villages. HH=household. ZMW=Zambian Kwacha; FRA=Food Reserve Agency.

Table 1E. 10: Full results: CRE-multinomial logit of choice of marketing channel made for the largest transaction of maize by net seller households

Variables	Average Partial Effects			
	Small scale traders	FRA	Large scale traders	Other households
Quantity of maize produced, kg	0.0000030	0.000039***	0.000012***	-0.000054***
	(0.0000081)	(0.0000089)	(0.0000036)	(0.000013)
Farmgate maize price (ZMW/kg, 2017=100)	0.0044	-0.036	0.044*	-0.013
	(0.033)	(0.033)	(0.025)	(0.022)
Farmgate FRA maize price (ZMW/kg, 2017=100)	0.081	0.46	-0.29	-0.24
	(0.42)	(0.43)	(0.28)	(0.27)
Age of the HH head (years)	-0.0012*	0.0010	-0.00071	0.00093**
	(0.00066)	(0.00075)	(0.00050)	(0.00043)
Education of household head (years)	0.00080	0.0018	-0.0019	-0.00073
	(0.0029)	(0.0030)	(0.0022)	(0.0022)
Full-time adult equivalents	-0.0068	0.0060	-0.0058	0.0065
	(0.012)	(0.012)	(0.010)	(0.009)
Male-headed household=1	0.012	-0.034	0.019	0.0036
	(0.020)	(0.029)	(0.020)	(0.017)
Distance to feeder road (cluster median, km) #	0.0029	-0.0041	0.0026	-0.0014
	(0.0072)	(0.0074)	(0.0048)	(0.0046)
Distance to tarmac road (cluster median, km) #	0.00036	-0.0016	0.00096	0.00030
	(0.0011)	(0.0010)	(0.0012)	(0.0006)
Distance to agricultural market (cluster median, km) #	0.00038	0.00066	-0.0011	0.00010
	(0.00086)	(0.00078)	(0.00074)	(0.00063)
Number of maize traders visiting village between May-October #	-0.0047	-0.0015	0.0049	0.0014
	(0.0050)	(0.0051)	(0.0046)	(0.0038)
HH owned a radio at the beginning of marketing period=1	0.0018	-0.0010	-0.0053	0.0045
	(0.029)	(0.034)	(0.025)	(0.021)

Table 1E. 10 (cont'd)

HH owned a cellphone at the beginning of marketing period=1	-0.013	-0.013	0.027	-0.0019
	(0.034)	(0.033)	(0.025)	(0.022)
HH owned a bicycle at the beginning of marketing period=1	-0.0080	-0.00082	0.022	-0.014
	(0.032)	(0.035)	(0.030)	(0.025)
Residuals from CRE-Tobit selection equation	0.000019	0.000051***	0.000024***	-0.000094***
	(0.000012)	(0.000011)	(0.0000053)	(0.000012)
Time fixed effects			Yes	
Province fixed effects			Yes	
CRE time averages			Yes	
Observations			7108	

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level in parentheses and bootstrapped with 500 replications to account for the generated regressor (CRE-Tobit residuals); [#]The cluster level medians were used for these variables even if they were collected at the household level in order to remove outliers. Cluster here refers to the standard enumeration area consisting of approximately 20 villages. HH=household. ZMW=Zambian Kwacha; FRA=Food Reserve Agency.

Table 1E. 11: Full results: CRE-exogenous switching POLS for maize output using alternate definition of liquidity status

Variables	**Average Partial Effects**	
	UC	**LC**
HH was liquidity constrained during planting time=1		-1561.5***
		(68.91)
Expected farmgate FRA price (ZMW/kg, 2017=100)	391.0	67.4
	(408.9)	(321.9)
Expected farmgate market maize price (ZMW/kg, 2017=100)	62.2	93.3
	(115.9)	(70.18)
Commercial basal fertilizer price (district median, ZMW/kg, 2017=100)	36.8	16.5
	(36.41)	(27.56)
Wage to weed 0.25 ha (district median, ZMW, 2017=100)	-3.67	0.088
	(2.175)	(0.806)
Maize seed price (district median, ZMW/kg, 2017=100)	38.7	-28.3*
	(23.86)	(12.61)
Age of the HH head (years)	-16.4***	-1.46
	(3.546)	(1.290)
Education of household head (years)	108.8***	14.5*
	(14.63)	(7.082)
Male-headed household=1	-385.5***	53.2
	(102.0)	(49.79)
Full-time adult equivalents	138.1*	56.9
	(66.98)	(30.56)
Landholding size (ha)	435.4***	118.3*
	(66.87)	(47.61)
Tropical livestock units	68.0**	35.5*
	(25.56)	(17.42)
Number of plows	314.9	43.4
	(185.5)	(133.5)
Number of harrows	526.0	4.57
	(634.3)	(617.9)
Number of ox-carts	463.7	-53.7
	(345.3)	(340.6)
HH experienced moisture shock in current growing season(t)=1	-111.4	-61.4
	(141.9)	(89.89)
Growing season rainfall (mm)	-1.06	-0.94
	(0.920)	(0.602)
HH has experienced long term moisture shock (16-yr MA) =1	49.0	9.39

Table 1E. 11(cont'd)

	(172.5)	(83.34)
Long run mean growing season rainfall (mm) (16-yr MA)	5.70**	2.40*
	(1.956)	(1.011)
Time fixed effects	Yes	
District fixed effects	Yes	
CRE time averages	Yes	
Observations	12,126	

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level in parentheses
LC= Liquidity Constrained; UC= Unconstrained; HH=household. ZMW=Zambian Kwacha; MA=moving average

Table 1E. 12: Test of hypotheses using alternate definition of liquidity status

Hypothesis	Effect of interest	APE
1	Liquidity constraint on the probability of being a net buyer	0.188*** (0.027)
	Liquidity constraint on the probability of being a net buyer	-0.221*** (0.028)
2	Expected FRA price on probability of being a net seller for LC HH	0.009 (0.065)
	Expected FRA price on probability of being a net seller for UC HH	0.055 (0.125)
	Market price on probability of being a net seller for LC HH	0.013 (0.013)
	Market price on probability of being a net seller for UC HH	0.009 (0.025)
3	Liquidity constraint on the probability of selling to a small-scale trader	-0.005 (0.013)
	Liquidity constraint on the probability of selling to FRA	-0.061*** (0.014)
	Liquidity constraint on the probability of selling to a large-scale trader	-0.019*** (0.006)
	Liquidity constraint on the probability of selling to other households	0.084*** (0.020)

Notes: Standard errors in parentheses are based on 500 bootstrap replications
APE= Average partial Effect; LC= Liquidity Constrained; UC= Unconstrained; HH=Household; FRA= Food Reserve Agency

Table 1E. 13: Falsification tests for validity of instruments

	Regression estimates from CRE-POLS of HH's liquidity status	Average Partial Effects from CRE-switching POLS of maize output (kg)	
		UC	**LC**
HH experienced a moisture shock in t+1 =1	0.013	18.0	-22.0
	(0.0302)	(329.0)	(97.24)
HH was liquidity constrained during planting time=1			-1268.3***
		(71.01)	(71.01)
Expected farmgate FRA price (ZMW/kg, 2017=100)	0.028	528.4	121.5
	(0.0814)	(792.7)	(243.4)
Expected farmgate market maize price (ZMW/kg, 2017=100)	-0.019	-35.1	-22.2
	(0.0173)	(213.4)	(64.61)
Commercial basal fertilizer price (district median, ZMW/kg, 2017=100)	-0.021*	191.0*	-29.4
	(0.00929)	(87.15)	(23.97)
Wage to weed 0.25 ha (district median, ZMW, 2017=100)	0.00069**	-3.51	0.016
	(0.000226)	(3.756)	(0.911)
Maize seed price (district median, ZMW/kg, 2017=100)	0.00097	53.9	-23.4
	(0.00331)	(40.91)	(14.47)
Age of the HH head (years)	0.0014***	-25.9***	-1.86
	(0.000399)	(5.807)	(1.408)
Education of household head (years)	-0.017***	131.8***	54.9***
	(0.00170)	(21.89)	(7.512)
Male-headed household=1	-0.054***	-254.6	-106.4*
	(0.0146)	(179.8)	(49.53)
Full-time adult equivalents	-0.00096	194.0	42.3
	(0.00685)	(109.6)	(36.21)
Landholding size (ha)	-0.0067*	567.2***	137.1***
	(0.00289)	(103.3)	(32.08)
Tropical livestock units	-0.0044**	68.9	38.0**
	(0.00150)	(36.71)	(11.65)
Number of plows	-0.028	180.5	112.0
	(0.0153)	(274.6)	(101.4)
Number of harrows	-0.035	210.6	782.9
	(0.0413)	(795.7)	(523.8)
Number of ox-carts	-0.044	357.6	-0.65
	(0.0285)	(500.0)	(248.1)
HH experienced moisture shock in current growing season(t)=1	-0.0038	-25.1	-151.0
	(0.0289)	(283.6)	(94.66)

Table 1E. 13 (cont'd)

Growing season rainfall (mm)	0.000086	0.31	-1.11
	(0.000168)	(1.747)	(0.649)
HH has experienced long term moisture shock (16-yr MA) =1	0.0062	192.3	-84.8
	(0.0204)	(283.1)	(88.03)
Long run mean growing season rainfall (mm) (16-yr MA)	-0.00052	6.81	2.32
	(0.000377)	(6.555)	(1.287)
HH experienced moisture shock in last growing season (t-1) (Instrument)=1	0.096***		
	(0.0234)		
Time fixed effects	Yes	Yes	
District fixed effects	Yes	Yes	
CRE time averages	Yes	Yes	
Observations	12,126	12,126	

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level in parentheses
LC= Liquidity Constrained; UC= Unconstrained; HH=household. ZMW=Zambian Kwacha; MA=moving average; FRA=Food Reserve Agency

Table 1E. 14: Effect of liquidity constraint on maize output: CRE-2SLS

Variable	**Coefficient**
HH was liquidity constrained during planting time=1	-2698.3*
	(1153.8)
Expected farmgate FRA price (ZMW/kg, 2017=100)	472.4
	(267.3)
Expected farmgate market maize price (ZMW/kg, 2017=100)	-48.8
	(97.81)
Commercial basal fertilizer price (district median, ZMW/kg, 2017=100)	-35.4
	(45.70)
Wage to weed 0.25 ha (district median, ZMW, 2017=100)	-1.57
	(2.057)
Maize seed price (district median, ZMW/kg, 2017=100)	27.4
	(18.53)
Age of the HH head (years)	-9.55**
	(3.006)
Education of household head (years)	59.3*
	(23.69)
Male-headed household=1	-482.4***
	(118.9)
Full-time adult equivalents	124.0*
	(55.97)
Landholding size (ha)	397.1***
	(55.91)
Tropical livestock units	57.0*
	(23.14)
Number of plows	197.0
	(169.1)
Number of harrows	504.8
	(589.1)
Number of ox-carts	389.5
	(303.3)
HH experienced moisture shock in current growing season(t)=1	-99.7
	(121.6)
Growing season rainfall (mm)	-0.64
	(0.755)
HH has experienced long term moisture shock (16-yr MA) =1	170.3
	(146.1)
Long run mean growing season rainfall (mm) (16-yr MA)	9.07***
	(1.443)

Table 1E. 14 (cont'd)

Time fixed effects	Yes
District fixed effects	Yes
CRE time averages	Yes
Observations	12126

Notes: *** p<0.01, ** p<0.05, * p<0.1; Standard errors clustered at HH level are in parentheses. Instrument for liquidity status at time t is a dummy variable that takes value 1 if there was a moisture shock at t-1 and 0 otherwise, F-stat for instrument is 16.27 (p<0.001). The test for endogeneity shows that we cannot reject the null of the liquidity constraint being exogenous (F-stat=1.84, p-value=0.175). LC= Liquidity Constrained; UC= Unconstrained; HH=household. ZMW=Zambian Kwacha; MA=moving average; FRA=Food Reserve Agency

Table 1E. 15: Average partial effects of sensitivity analysis using different measures of prices (CRE-exogenous switching POLS for maize output)

	Model 1		Model 2	
	UC	**LC**	**UC**	**LC**
HH was liquidity constrained during planting time=1		-1273.0***		-1272.0***
		(70.97)		(70.97)
Expected farmgate FRA price (ZMW/kg, 2017=100)	525.4	122.3	523.9	119.7
	(788.4)	(242.9)	(789.2)	(243.3)
Expected farmgate market maize price (ZMW/kg, 2017=100)	-291.1	17.8	-182.0	-6.44
	(238.6)	(64.48)	(235.4)	(66.23)
Commercial basal fertilizer price (district median, ZMW/kg, 2017=100)	194.1*	-30.4	189.3*	-30.4
	(85.04)	(23.51)	(85.58)	(23.96)
Wage to weed 0.25 ha (district median, ZMW, 2017=100)	-4.30	0.016	-3.83	-0.019
	(3.869)	(0.861)	(3.810)	(0.868)
Maize seed price (district median, ZMW/kg, 2017=100)	54.2	-23.0	54.5	-22.6
	(41.40)	(14.52)	(41.43)	(14.51)
Age of the HH head (years)	-26.2***	-1.87	-26.1***	-1.87
	(5.820)	(1.410)	(5.816)	(1.410)
Education of household head (years)	131.3***	55.0***	131.5***	55.0***
	(21.86)	(7.503)	(21.85)	(7.499)
Male-headed household=1	-252.6	-106.2*	-254.6	-106.4*
	(179.7)	(49.56)	(179.6)	(49.55)
Full-time adult equivalents	191.5	41.7	192.7	42.1
	(109.6)	(36.20)	(109.5)	(36.22)
Landholding size (ha)	566.3***	137.4***	566.3***	137.3***
	(103.2)	(32.01)	(103.3)	(32.05)
Tropical livestock units	70.3	38.0**	69.7	37.9**
	(36.75)	(11.61)	(36.75)	(11.64)
Number of plows	184.1	111.5	182.9	111.9

Table 1E. 15 (cont'd)

	(274.9)	(101.5)	(274.7)	(101.5)
Number of harrows	213.6	781.3	208.2	782.6
	(797.3)	(523.7)	(797.4)	(523.5)
Number of ox-carts	360.2	-0.45	361.2	-0.77
	(500.9)	(247.9)	(500.7)	(247.9)
HH experienced moisture shock in current growing season(t)=1	28.1	-174.0*	6.54	-171.1*
	(246.5)	(85.92)	(246.3)	(85.80)
Growing season rainfall (mm)	0.26	-1.10	0.35	-1.10
	(1.746)	(0.640)	(1.741)	(0.639)
HH has experienced long term moisture shock (16-yr MA) =1	198.2	-85.1	192.7	-84.4
	(281.4)	(88.30)	(281.5)	(87.67)
Long run mean growing season rainfall (mm) (16-yr MA)	6.58	2.18	6.53	2.22
	(6.520)	(1.249)	(6.536)	(1.255)
Time fixed effects	Yes		Yes	
District fixed effects	Yes		Yes	
CRE time averages	Yes		Yes	
Observations	12,126		12,126	

Notes: *** p<0.01, ** p<0.05, * p<0.1. The estimates are average partial effects. Standard errors in parenthesis are clustered at HH level. In Model 1 expected farmgate maize market price that was computed by taking MA of retail maize prices for the months of July, August, and September. In Model 2 it was computed by taking the MA of prices over the peak maize marketing season May-October. Both prices were adjusted for cost of transport from homestead to district administrative unit. LC= Liquidity Constrained; UC= Unconstrained; HH=household. ZMW=Zambian Kwacha; MA=moving average; FRA=Food Reserve Agency.

Table 1E. 16: Average partial effects of sensitivity analysis for different measures of prices (CRE-ordered probit of quantity based maize market position)

Variables	**Model 1**			**Model 2**		
	Net-buyer	**Autarkic**	**Net-seller**	**Net-buyer**	**Autarkic**	**Net-seller**
Quantity of maize produced, kg	-0.00012***	-0.000020***	0.00014***	-0.00012***	-0.000020***	0.00014***
	(0.000016)	(0.0000015)	(0.000016)	(0.000016)	(0.0000015)	(0.000016)
Farmgate maize price (ZMW/kg, 2017=100)	-0.0036	-0.00060	0.0042	0.0092	0.0016	-0.011
	(0.00934)	(0.00158)	(0.0109)	(0.0113)	(0.00191)	(0.0132)
Farmgate FRA maize price (ZMW/kg, 2017=100)	-0.057	-0.0097	0.067	-0.066	-0.011	0.077
	(0.107)	(0.0180)	(0.125)	(0.105)	(0.0177)	(0.123)
Age of the HH head (years)	0.00021	0.000035	-0.00024	0.00021	0.000035	-0.00024
	(0.000229)	(0.0000385)	(0.000267)	(0.000229)	(0.0000385)	(0.000267)
Education of household head (years)	0.0017	0.00029	-0.0020	0.0017	0.00029	-0.0020
	(0.00114)	(0.000189)	(0.00133)	(0.00114)	(0.000189)	(0.00133)
Full-time adult equivalents	0.021*	0.0038*	-0.025*	0.021*	0.0038*	-0.025*
	(0.00881)	(0.00180)	(0.0106)	(0.00881)	(0.00180)	(0.0106)
Male-headed household=1	0.013**	0.0021**	-0.015**	0.013**	0.0021**	-0.015**
	(0.00460)	(0.000827)	(0.00539)	(0.00460)	(0.000827)	(0.00538)
Distance to feeder road (cluster median, km) #	0.0014	0.00023	-0.0016	0.0016	0.00027	-0.0018
	(0.00155)	(0.000265)	(0.00181)	(0.00153)	(0.000263)	(0.00179)
Distance to tarmac road (cluster median, km) #	-0.00031	-0.000052	0.00036	-0.00031	-0.000052	0.00036
	(0.000268)	(0.0000466)	(0.000314)	(0.000267)	(0.0000466)	(0.000314)
Distance to agricultural market (cluster median, km) #	0.00021	0.000036	-0.00025	0.00019	0.000032	-0.00022
	(0.000336)	(0.0000564)	(0.000393)	(0.000336)	(0.0000565)	(0.000392)
Number of maize traders visiting village between May-October #	-0.0019	-0.00032	0.0022	-0.0020	-0.00033	0.0023
	(0.00209)	(0.000355)	(0.00245)	(0.00208)	(0.000353)	(0.00243)
HH owned a radio at the beginning of marketing period	-0.0073	-0.0012	0.0086	-0.0074	-0.0013	0.0087
	(0.0120)	(0.00205)	(0.0141)	(0.0120)	(0.00206)	(0.0141)

Table 1E. 16 (cont'd)

HH owned a cellphone at the beginning of marketing period	0.0065	0.0011	-0.0075	0.0061	0.0010	-0.0072
	(0.0134)	(0.00221)	(0.0156)	(0.0133)	(0.00221)	(0.0155)
HH owned a bicycle at the beginning of marketing period	0.0067	0.0011	-0.0078	0.0065	0.0011	-0.0077
	(0.0131)	(0.00222)	(0.0153)	(0.0131)	(0.00222)	(0.0153)
Time fixed effects		Yes			Yes	
District fixed effects		Yes			Yes	
CRE time averages		Yes			Yes	
Observations		12126			12126	

Notes: *** p<0.01, ** p<0.05, * p<0.1; [#]The cluster level medians were used for these variables even if they were collected at the household level in order to remove outliers. Cluster here refers to the standard enumeration area consisting of approximately 20 villages. All estimates in the table are average partial effects. Standard errors in parenthesis are clustered at HH level. In Model 1 farmgate maize market price refers to MA of retail maize prices for July, August, and September. In Model 2 it refers to MA of prices over the peak maize marketing season (May-October). Both prices were adjusted for cost of transport from homestead to district administrative unit. HH=household. ZMW=Zambian Kwacha. FRA=Food Reserve Agency.

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CHAPTER 2

HOW DO INTERNATIONAL TRADE REGULATIONS AND RULES GOVERNING DOMESTIC FERTILIZER MARKETS AFFECT FERTILIZER IMPORTS? EVIDENCE FROM A CROSS-COUNTRY PANEL

2.1 Introduction

The use of inorganic fertilizers in agriculture has been shown to increase labor and land productivity, and thus contribute to economic development (Murgai, 2001; Restuccia, Yang and Zhu, 2008; McArthur and McCord, 2017). Their importance in the developing world is heightened as more than half of the labor force in many low-income countries is dependent upon agriculture for their livelihoods (World Bank, 2019a). However, fertilizer consumption remains low in many parts of the developing world.[26] Several demand and supply factors have been identified as contributing to the low usage of fertilizers.[27] Government efforts to increase fertilizer consumption in developing countries have primarily focused on heavy subsidization of fertilizer products. In sub-Saharan Africa (SSA), for example, this led to large public sector expenditures but only marginal improvements in fertilizer usage while crowding out private sector participation in the fertilizer sector (see reviews by Druilhe and Barreiro-Hurlé, 2012; Jayne and Rashid; 2013; Jayne et al., 2018; and Holden, 2019, among others). As a result, fertilizer subsidy programs have come under harsh criticism and there has been an increased emphasis on promoting private sector investment at all levels of the fertilizer value chain as a means of improving farmers' access to inorganic fertilizers (Jayne and Rashid, 2013; IFDC, 2013, Ariga et al., 2018).

The interest in the development of vibrant private sector-led fertilizer markets (and agricultural input and output markets more generally) has led to a recognition of the importance of creating an enabling environment for markets to function efficiently (Poulton, Kydd, and

[26] In 2018, the fertilizer consumption per hectare in of cropland averaged 11 kg in low-income countries and 26 kg for sub-Saharan Africa (SSA), much lower than the world average of 126 kg (World Bank, 2018a).
[27] Some of these are: risk-aversion (Binswanger and Sillers, 1983; Giné, and Yang, 2009), behavioral biases (Duflo, Kremer and Robinson, 2011), externalities in learning (Conley and Udry, 2010), heterogeneity in returns to fertilizer (Marenya and Barrett, 2009; Suri, 2011, Kopper, Jayne and, Snapp (2020), Burke, Snapp and Jayne (2020), Chamberlin, Jayne, and Snapp (2021)), inadequate public goods such as roads, market information, and well defined fertilizer laws (Kelly, Adesina, and Gordon, 2003), high cost of imported fertilizer due to market power in the global fertilizer value chain (Hernandez and Torero, 2013), and trade restrictions and transport bottlenecks (Bumb et al, 2011). Morris et al. (2007) provide a detailed review of demand and supply factors affecting fertilizer use in African agriculture.

Dorward, 2006; Bumb et al., 2011; Ariga et al., 2018). The enabling environment encompasses the policies, regulations, institutional infrastructure, and other state actions that support and protect stakeholders that participate in private markets (Christy et al., 2009; Diaz-Bonilla et al., 2014).

For the fertilizer sector, the enabling environment for international trade is of particular importance because the production of fertilizers is concentrated in relatively few countries, thus rendering much of the world dependent upon fertilizer imports to meet its domestic fertilizer needs (Hernandez and Torero, 2013).[28] The need for raw materials and the large economies of scale associated with production of fertilizer are partly responsible for the concentration of fertilizer production in a small number of countries. The development of domestic fertilizer manufacturing in some low-income countries has been gaining traction (Poulton et al., 2006), yet most low-income and lower-middle income countries continue to be net importers of fertilizer products. For example, fertilizer imported as a percentage of total fertilizer used in agriculture in 2018 was 98% and 96% for SSA and Latin America, respectively (FAOSTAT, 2018a).

Much of the empirical research on international fertilizer trade-related issues is focused on studying fertilizer prices and margins between import and domestic fertilizer prices (Hernandez and Torero, 2013; Shimeles et al., 2015; Ncube et al., 2016, Khabarov and Obersteiner, 2017). These studies note that domestic market prices of fertilizers are quite high relative to farmers' purchasing power and suggest that non-competitive behavior and the presence of market power in international trade of fertilizers may contribute to the high prices. While it is acknowledged that domestic fertilizer markets in developing countries often have very few importing firms, it is not clear whether this is a sign of non-competitive behavior or simply an outcome of the peculiar nature of the industry (capital intensive, large economies of scale, and relatively low demand for fertilizers in developing countries) (Shimeles et al., 2015; Vilakazi and Roberts, 2018).

One plausible reason behind the small number of market players and low market activity in the fertilizer import sector could be redundant market regulations that impede the entry of new players. Excessively stringent state regulation in the fertilizer sector is often perceived to suggest collusion between the state and powerful market players in the fertilizer industry (Benson and Mogues, 2018; Vilakazi and Roberts, 2018) and may have an adverse effect on farmers' access to

[28] The five largest producers of fertilizers in 2018 produced 60% of the world's combined volume of nitrogenous (N), phosphatic (P) and potassic (K) fertilizer products. These were China (25%), Russian federation (11%), India (8.6%), USA (8.3%), and Canada (7.8%) (FAOSTAT, 2018a).

fertilizers in developing countries. Case studies on Zambia and South Africa revealed that the dismantling of fertilizer cartels led to the entry of more players into the fertilizer industries of both countries (Ncube et al. 2016; Vilakazi and Roberts, 2018). In another study, Uganda was found to have relatively low government intervention in its fertilizer markets as well as the lowest margins between import and retail fertilizer prices as compared to Malawi, Nigeria, and Kenya (Hernandez et al., 2018). Similarly, Hernandez and Torero (2018) noted that although Nigeria produced enough fertilizers to meet the demand of all of SSA in 2018, 80% of the production was exported to Brazil and Argentina due to high trade barriers among African countries, thus foregoing opportunities for intra-African fertilizer trade. These revelations are based on case studies and descriptive statistics, but rigorous empirical analysis of the potential effects of different types of market regulations on fertilizer import market outcomes is warranted. We address this knowledge gap by focussing on two types of regulations that are likely to affect fertilizer imports. The first are general international trade regulations imposed by a given nation on any imported commodity. The second are those that govern the ease of importing fertilizers and selling them in the domestic market. We focus on the effects of these regulations on fertilizer imports, which is our outcome of interest given the aforementioned importance of imports in meeting domestic fertilizer demand.

This study also builds on a growing body of literature that shows that regulations that are related to facilitation of international trade are important determinants of the flow of international trade (Anderson and Wincoop, 2004; Clark, Dollar, and Micco, 2004; Djankov, Fruend, and Pham, 2010). The growing global acceptance of the importance of trade facilitation is also reflected by the passing of the Trade Facilitation Agreement (TFA) by the World Trade Organization (WTO) in 2017 and the founding of the African Continental Free Trade Agreement (AfCFTA) in 2018.[29] Regulations on international trade are likely to affect fertilizer imports because of the importance of fertilizer imports in meeting fertilizer consumption demands across the world. Similarly, there is much speculation that regulations on domestic fertilizer markets in some developing countries area unnecessarily stringent and likely to hinder the development of fertilizer markets. Some examples of these stringent regulations are expensive and time-consuming procedures to obtain

[29] The TFA aims at reducing the red tape associated with the movement of goods across international borders. The process is expected to ultimately "improve transparency, increase possibilities to participate in global value chains, and reduce the scope of corruption" (WTO, n.d., a) The AfCFTA led to the creation a free trade area within Africa that includes almost all Africa n nations and aims at bringing prosperity by exploiting the potential of trade within the continent (Maliszewska and Ruta, 2020).

fertilizer import licenses and permits, many of which have to be renewed frequently and with changes in the volume of fertilizer being transacted (NML and AFAP, 2017).[30] Many countries in SSA have multiple institutions that regulate fertilizer trade and distribution, leading to conflicts (NML and AFAP, 2016a; 2016b; 2016c; 2016d). These, coupled with inadequate port infrastructure, multiple road checks, and lack of a single window system create bottlenecks for fertilizer imports (USAID, 2015).[31]

On the other hand, it is sometimes argued that the existing regulations may be necessary to prevent illicit trade and the accumulation of excessive market power, and, in the case of many developing countries, to compensate for the lack of market mechanisms to ensure the quality and safety of products.[32] For example, ensuring the quality of fertilizer products may require direct government control of the products being commercialized in developing countries where consumer awareness might be low and state capacity to monitor labels and enforce standards is weak.[33] Similarly, customs and border agencies must maintain a delicate balance between facilitating the transfer of goods across borders and preventing illicit trade. The level of control and restriction placed by these agencies can often be an outcome of the safety of borders and the amount of illicit activity that is likely to occur (Gerstein et al., 2018). Further, the existence of oligopolies in the fertilizer industry could be the outcome of the nature of the industry, such as being a capital-intensive industry with large economies of scale (Shimeles et al., 2015). More importantly, it is not clear whether reduced government intervention in international trade and domestic fertilizer markets necessarily leads to the desired fertilizer market outcomes.

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[30] For example, the World Bank's Enabling the Business of Agriculture (EBA) report for 2017 noted that Nigeria requires an import permit for each shipment of fertilizer; the permit is valid for only 12 months but takes 90 days to obtain from the government. Further, 37% of the 67 countries surveyed for the EBA report, imposed restrictions on the volume of fertilizer that can be imported, potentially hurting the negotiating power of the importers with sellers in the international market (World Bank, 2017a).

[31] A single window system is a tool for trade facilitation. It is defined as "a system that allows traders to lodge information with a single body to fulfill all import and export related regulatory requirements" (UNECE, 2003, p.2).

[32] For example, the deregulation of the fertilizer industry in Nepal initially improved fertilizer supply but also led to deterioration of quality and untimely supply of fertilizers (Shrestha, 2010). Partial decontrol of the fertilizer industry in India in 2010 led to a sharp rise in domestic prices and a decline in demand for fertilizers during 2010-12, raising concerns that small and marginal farms would be rendered unviable (Sharma, 2012). Omamo (2003) showed that fertilizer prices in Uganda continued to be high despite minimal government intervention and low margins between import and retail prices. In Kenya, Omamo and Mose (2011) found no statistically significant relationship between a perceived positive business environment and domestic fertilizer trade after liberalization of the fertilizer markets in the country.

[33] This has been shown to be true for food products by Roe and Sheldon (2007) and Delleck, Kerchbamer, and Sutter (2009), but could apply in principle to fertilizer products as well.

We conduct a rigorous cross-country panel data analysis to understand whether differences in regulations governing international trade and domestic fertilizer markets are associated with the volume of fertilizer imports. We measure regulations related to international trade using the World Bank's Doing Business data on Trading Across Barriers (TAB). The TAB measures the time and cost incurred in complying with a country's international trade regulatory requirements (such as preparing and submitting documents and clearing customs and inspections that are representative of a standard international transaction taking place at the country's port or land border).[34] Further, to capture fertilizer market specific regulations, we draw upon the World Bank's Enabling the Business of Agriculture (EBA) data. Specifically, we use information on regulations governing the ease with which private entities within the country can import fertilizers and register a new fertilizer product for sale within the country. [35] Our analytical sample when analyzing the TAB data consists of 156 countries observed over five years (2014-2018). Our analytical sample when using the TAB and EBA data jointly consists of 59 countries for two years (2016-2017).

Our paper makes the following contributions to the literature. First, to the best of our knowledge, it is the first cross-country panel data analysis of the effects of international trade regulations and rules governing domestic fertilizer markets on fertilizer import volumes. Previous cross-country analyses related to fertilizer imports have focused on fertilizer prices (Hernandez and Torero, 2013; Shimeles et al., 2015). Through our analysis we provide rigorous empirical evidence about the link between market regulations and fertilizer imports and thus the availability of fertilizers in fertilizer import-dependent developing countries. Finally, our analysis provides empirical evidence on whether and what types of regulations (among the ones that we test) could potentially be hindering the supply of fertilizers, especially in countries that are dependent on imports for meeting their domestic fertilizer consumption needs. Thus, our paper contributes to a better understanding of what constitutes the enabling environment for fertilizer imports.

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[34] The TAB data have been used as a proxy for trade-related regulatory policies by Hoekman and Nicita (2011), who find that trade regulations are at least as important as traditional border policies in impeding trade. Djankov, Fruend, and Pham (2010) in their pioneering paper using the TAB data found that a one-day delay in shipping of a product reduces trade by more than 1% and the impact is greater for time sensitive goods such as agricultural products. Portugal-Perez and Wilson (2012) use the TAB data and conclude that trade facilitation reforms improve the export performances of developing countries.

[35] Divanbeigi and Saliola (2017) used the EBA data to compute measures of quality and efficiency of regulations governing the agricultural sector and find that these are positively and significantly associated with the agricultural productivity of the country. The EBA data have also been used by researchers to study legal and regulatory issues related to gender (Panter and Arekapudi, 2018), information and communication technology (Kayumova, 2017).

The rest of the paper is organized as follows. In the next section we present a brief conceptual framework and discuss potential mechanisms through which regulations may affect fertilizer imports. We also state our hypothesis and expected results. In the subsequent section we discuss the data used in the paper and follow it by the methodology. We then present the results and discussion and conclude the paper.

2.2 Conceptual framework and hypothesis

In the previous section we discussed how some countries continue to place stringent regulations on the trade of fertilizer products. There is concern that some of these regulations may be the outcome of collusion between the state and a small number of powerful market players that maintain their dominance in the import of fertilizers and are likely to charge higher than competitive prices. On the other hand, these regulations may be an outcome of the government's efforts to ensure the quality and safety of fertilizers that are not being met by market mechanisms. Some countries may also face relatively greater threats of illicit trade across their borders and may need to place more stringent controls on their borders.

If increased regulations are indeed an outcome of collusion between the state and powerful market players and/or the reluctance of government to reform regulations, then we would expect a removal or a reduction in the severity of these regulations, *ceteris paribus*, to lead to improvements in fertilizer market outcomes. Firstly, there is likely to be an increase in the quantity supplied and in the variety of fertilizers available due to an increased number of players and/or increased quantity of fertilizers in the market (for example, due to relaxation of quantity restrictions on imports). The increased competition and reduction of excess profit should lead to a reduction in fertilizer prices and increased fertilizer quantity demanded or overall demand (due to reduced fertilizer prices and/or improved quality and variety of products). If the supply of fertilizer is price elastic, an upward shift in demand for fertilizers (due to reasons other than lower prices such as more variety and improved quality of fertilizers) should further increase the quantity of fertilizer supplied. Thus, an increase in fertilizer imports is expected, especially if the country is heavily dependent upon imports to meet its fertilizer demand. Finally, increased fertilizer products may also be imported for use in domestic production of fertilizer blends that are then used for domestic consumption or exported to other countries. On the contrary, if existing regulations reflect the necessary checks needed to ensure quality, safety, and prevention of criminal activities in the country, a relaxation of these regulations may, in fact, have a negative effect on fertilizer market outcomes.

A large body of evidence that we discussed earlier, though not based on rigorous empirical analysis, suggests that at least some of the regulations imposed on the fertilizer markets and the import sector by some countries may be redundant. Thus, we hypothesize that more stringent or onerous regulations on international trade in general and fertilizer trade in particular are negatively associated with the volume of fertilizer imported by the country. The regulations related to international trade are measured as the time and cost of complying with a nation's regulatory requirements for ensuring successful import of goods across its international border. The regulations pertaining to the fertilizer sector are measured as categorical variables that indicate the level of government control of the sector. (All of these variables are discussed in greater detail below.) It is expected that more time and greater cost incurred in ensuring successful import of goods across borders will be negatively correlated with the volume of fertilizer imported. Similarly, the higher the level of government's control of the fertilizer sector, the lower the volume of fertilizer imported is expected to be.

2.3 Data

The data used in this study are drawn from several sources which are summarized in Table 2.1. We begin with discussing the main variables of interest, i.e., the various measures of regulations that govern international trade and the fertilizer sector. The World Bank's Trading Across Border (TAB) component of the Doing Business project provides comparable cross-country data on the time and costs incurred in meeting the documentary and border compliance requirements related to importing goods across international borders. These are used as proxies for the extent of regulation exercised by the government over international trade.[36] Documentary compliance includes activities such as gathering information to complete customs clearance or obtaining a certificate of origin, issuance and stamping of related documents, presenting port terminal receipts to port authorities, submitting a customs declaration to the customs agency in person or electronically, etc. It does not include submitting or obtaining documents needed to produce or sell the product on the domestic market, cost of insurance, any informal payments for

[36] The TAB data are available from 2006-2018. However, due to changes in methodology, the data pertaining to 2006-2013 are not comparable with that of 2014 and beyond. Thus, we choose to conduct our analysis for the most recent years (2014-2018), during which the data are comparable (2014-2018).

which a receipt is not issued, or domestic transport costs from the port to the warehouse (Doing Business, n.d.). The time and costs incurred in meeting border compliance include the time and costs associated with hiring a custom broker, conducting pre-shipment, physical, technical, and/or security inspection by customs and port/border authorities, processing an import declaration, scanning and weighing by customs, waiting in queue outside the port/border for entry, and time for handling, unloading, and storing at the port/border. Not all components are required by all countries; in such cases the associated time and cost of the specific component is zero (Doing Business, n.d.). These data are collected through a questionnaire administered to private sector experts on the international trade logistics of each country. The questionnaire is set up as a case study of the import of a standardized shipment of a 15 metric ton auto part (or a similar product of the contributor's choice). This is done in order to make the data comparable across countries and is based on the procedure developed by Djankov, Fruend, and Pham (2010). The time and costs computed cover the procedures that will occur in the majority of international trade transactions and represent a standard case of importing a commodity across the country's border (Doing Business, n.d.). The TAB measures have been used widely in the trade literature to represent the time and costs faced in international trade of non-sector specific goods (Djankov, Fruend, and Pham, 2010; Freund, and Rocha, 2011; Hoekman and Nicita, 2011; Portugal-Perez and Wilson, 2012) and for perishable agricultural goods (Djankov, Fruend, and Pham, 2010; Freund, and Rocha, 2011). Moreover, regulatory barriers on a chemical product like fertilizers, which has potential health and environmental implications, are likely to be higher than on an auto-product. Thus, it is likely that that the TAB time and costs represent a lower bound on the regulatory barriers faced in the movement of fertilizers across borders.

Table 2. 1: Description of the variables used in the analysis

Variable name	Source	Unit of measurement	Description
Fertilizer imports	FAOSTAT	MT	Sum of imports of Nitrogenous (N), Phosphatic (P), and Potassic (K) fertilizers [a]
Fertilizer exports	FAOSTAT	MT	Same as above
Fertilizer production	FAOSTAT	MT	Data collected through questionnaires administered to country officials and augmented with official publications where available
Time of documentary compliance	DB	hours	Time and cost incurred in "obtaining, preparing, and submitting documents during the transport, clearance, inspections, and port or border handling" required for completion of trade (World Bank, 2017b, p. 150).
Cost of documentary compliance		% current GNI per capita [b]	
Time of border compliance	DB	hours	Time and cost incurred in "compliance with the economy's customs regulations and with regulations relating to other inspections that are mandatory in order for the shipment to cross the economy's border as well as handling that takes place at its port or border" (World Bank, 2017b, p. 150).
Cost of border compliance		% current GNI per capita [b]	
Requirement of a permit to import fertilizers	EBA	Categorical variable	1 = no permit is required, 2 = a permit is required but there is no restriction on the number of shipments or volume of fertilizer transacted, 3 = a permit is required and there are restrictions either on the number of shipments or on the volume of fertilizer transacted
Registration of new fertilizer products to be sold on the domestic market	EBA	Categorical variable	1 = no registration is required, 2 = registration is required only once when a new product is introduced, 3 = registration is required and must be periodically renewed.
Gross Domestic Product[c]	WDI	constant 2010 USD	
Agricultural GDP	WDI	% of total GDP	
Population	WDI	number	
Rural population	WDI	% of total population	
Population dependent on agriculture	WDI	% of total population	

Table 2. 1 (cont'd)

Annual average rainfall received by the country	Harris et al. (2020)	mm	
Area harvested	FAOSTAT	hectares	Sum of area harvested of all temporary and permanent crops, including cereals, pulses, oilseeds, sugar crops, fibers, roots and tubers, vegetables, fruits, and treenuts.[d]
Cropland	FAOSTAT	hectares	Land used for cultivation of crops and includes the total of areas under "Arable land" and "Permanent crops". (FAOSTAT, n.d.,c) [e]
Government effectiveness index	WGI	Percentile rank (0-100)	See footnote f
Control of corruption index	WGI	Percentile rank (0-100)	See footnote g
Landlocked	Head and Mayer (2014)	Indicator variable	=1 if country is landlocked, =0 otherwise.
Latitude and longitude	WorldMaps (n.d.)	Geographical coordinates	

Notes: MT= Metric Tons; DB= Doing Business project, World Bank; EBA= Enabling the Business of Agriculture, World Bank; WDI= World Development Indicators; WGI= World Governance Indicators. [a] FAOSTAT compiles these data from several sources, chief among which is UN COMTRADE for a wide range of fertilizer products. This is augmented with imputations and quality checks by industry experts. The fertilizer products are converted to their nutrient components using standard conversion rates. See FAOSTAT (n.d., a) for details. [b] The costs of documentary and border compliance are recorded in current USD in the original data. Converting these values to constant values is difficult because the World Bank's deflators have different base years for different countries. Instead, we followed the approach used by the EBA project and express the cost as a percent of current GNI per capita (computed using the Atlas method so that the effect of sudden fluctuations in the exchange rate is reduced). An alternate approach would be first convert each cost term to its purchasing power (PPP) equivalent USD and then convert those values to constant terms using the PPP deflator. However, the PPP is not preferred by the World Bank due to concerns related to methodology, geographical coverage, and quality, and we follow suit (World Bank, n.d.). [c] We choose to use the GDP instead of the GNI to control for the size of a country's economy as it is more common in literature. The GDP variable is also highly positively correlated with the GNI (correlation coefficient of 0.98). [d] Here area harvested refers to "area from which a crop is gathered"; it excludes the "area from which, although sown or planted, there was no harvest due to damage, failure, etc. It is usually net for temporary crops and sometimes gross for permanent crops" FAOSTAT (n.d., b). [e] Arable land refers to "The total of areas under temporary crops, temporary meadows and pastures, and land with temporary fallow;" it "excludes land that is potentially cultivable but is not normally cultivated" (FAOSTAT, n.d., c). Permanent crops refer to "Land cultivated with long-term crops which do not have to be replanted for several years", such as coffee, cocoa, trees, shrubs, and nurseries; it does not include permanent meadows and pastures (FAOSTAT, n.d., c). [f] It measures the "perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies" (Kaufmann, Kraay, and Mastruzzi, 2010, p. 4). [g] It measures the "the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as 'capture' of the state by elites and private interests" (Kaufmann, Kraay, and Mastruzzi, 2010, p).

The measures of fertilizer specific regulations are sourced from the World Bank's Enabling the Business of Agriculture (EBA) initiative. We utilize the EBA data on the regulations governing the import and sale of fertilizers. First among them is a variable indicating whether a private entity must obtain an import permit to import fertilizers into the country. In the EBA dataset, this is recoded as a categorical variable that takes on the value 1 if no permit is required, 2 if a permit is required but there is no restriction on the number of shipments or volume of fertilizer transacted, and 3 if a permit is required and there are restrictions either on the number of shipments or on the volume of fertilizer transacted. The second EBA variable leveraged in this study measures whether a private entity needs to register a new fertilizer product before selling it commercially on the domestic market. In the EBA dataset, this variable takes on the value 1 if no registration is required, 2 if the registration is required only once when a new product is introduced, and 3 if the registration is required and must be periodically renewed. For purposes of the regression analysis (described below), each of the EBA variables was converted to two dummy variables with the first category as the base.[37]

Data for country level fertilizer imports (measured in metric tons) are drawn from FAOSTAT. The import data are the sum of imports of Nitrogenous (N), Phosphatic (P), and Potassic (K) fertilizers. Data on volume of fertilizer exported and produced were also obtained from the same source. Other data used in the analysis include country and year-wise data on Gross Domestic Product (GDP) (total GDP and the agricultural GDP as a percentage of total GDP), total crop land or area harvested, annual rainfall, population (total, percent rural, and percent dependent upon agriculture), indicators of government effectiveness and control of corruption, and an indicator variable for the landlocked status of a country. (See Table 2.1 for additional details on the variable definitions and sources, and Table 2A.1 in Appendix 2A for summary statistics for all variables included in the analysis.)

Overall, when we focus our analysis on the variables from the TAB data (time and costs of border and documentary compliance), our analytical sample consists of a balanced panel covering

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[37] Other information pertaining to fertilizer markets included in the EBA data included data on the cost of obtaining an import permit and registering a new fertilizer product. Unfortunately, the methodology for collecting these data changed over the period of our study and thus the data are not comparable over time. Comparable data was available on whether a country's laws prohibit sale of mislabeled fertilizers. However, there was very little variation in this variable; thus, we excluded it from our analysis. (Only four out of the 62 countries included in the EBA data reported not having a law that prohibited the sale of mislabeled fertilizers.)

156 countries over five years (2014-2018), for a total of 780 country-year observations.[38] When we add the fertilizer-related EBA variables to the analysis, our analytical sample declines to 59 countries over two years (2016 and 2017) making a total of 118 country-year observations. The countries were selected primarily on the basis of data availability.[39] (See tables 2A.2 and 2A.3 in Appendix 2A for the list of countries included in and excluded from the analysis, respectively.)

As shown in Table A4 in Appendix 4, all 156 countries in our full analytical sample imported some amount of fertilizer in the most recent year of the analysis (2018). In 2018, an average of 630.5 and median of 108.8 thousand MT of fertilizer was imported. The distribution of fertilizer imports is highly skewed with the top four importers (Brazil, USA, India, and China, in that order) constituting 42% of the global fertilizer imported. As for exports, in 2018, 125 countries exported some amount of fertilizer. The mean amount exported was 771.5 thousand MT and the median was 99.2 thousand MT. The top three exporting countries (Russia, China, and Canada, in that order) accounted for 42% of the total fertilizer exported. The production of fertilizers was also skewed with only 77 countries producing some amount of fertilizer domestically in 2018 and the top five countries (China, Russia, India, USA, and Canada, in that order) accounting for 60% of the world's production of fertilizers; the mean quantity produced was 2,705.3 thousand MT and the median was 610.0 thousand MT.[40]

Turning to the TAB data, the variables for time and costs incurred in documentary and border compliance for the year 2018 are found to be higher among low and lower middle income countries as compared to upper middle and high income countries (Figures 2.1 and 2.2). Similarly, restrictions on the import of fertilizers were much more stringent for low and lower middle income countries as compared to upper middle and high income countries (Table 2A.5, Appendix 2A). These observations are in line with the perception that bureaucratic barriers to trade in general and to fertilizer trade specifically are higher in low and lower middle income countries. In contrast, the regulatory barrier to the introduction of new fertilizers is found to be higher in upper middle and

[38] Data on agricultural GDP were not available for Barbados and Libya, thus reducing our analytical sample to 770 observations (154 countries over 5 years) when including it as a control. Our results are robust to this minor change.
[39] The TAB data are available for a total of 187 countries for the study period. However, corresponding information on fertilizer imports and important control variables are available for only 156 countries. Similarly comparable EBA data for 2016 and 2017 are available for 62 countries, but corresponding information on fertilizer imports is missing for three countries, leaving 59 countries in our sample.
[40] The statistics for the pooled data of 2014-2018 were very similar and are presented in Table 2A.4, Appendix 2A.

high income countries as compared to low and lower middle income countries (Table 2A.6, Appendix 2A). [41]

Figure 2.1: Mean time incurred in documentary and border compliance by income group, 2018

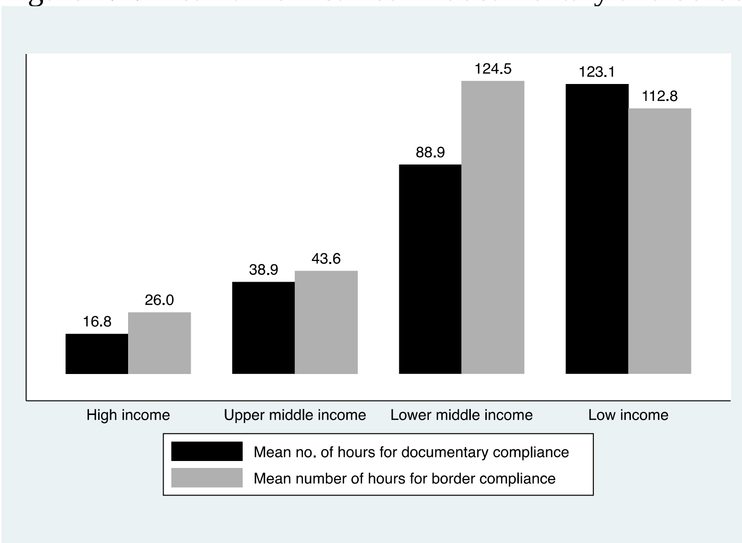
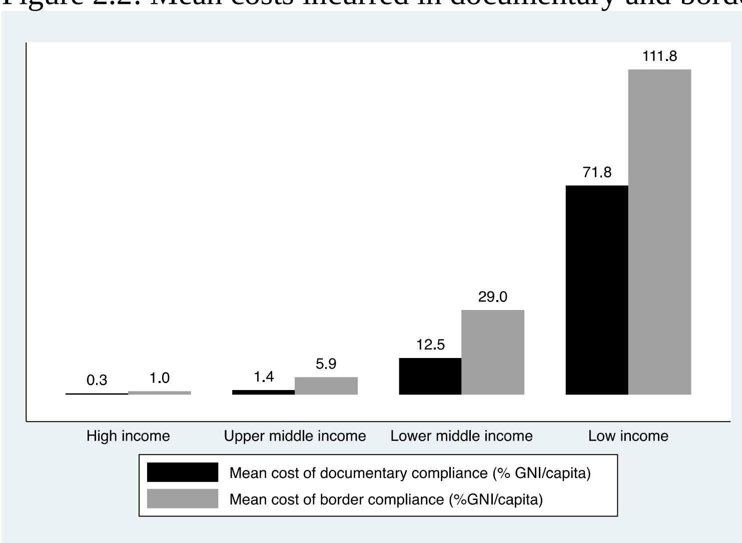


Figure 2.2: Mean costs incurred in documentary and border compliance by income group, 2018



2.4 Methodology

2.4.1 Empirical method

We begin by describing the methodology for testing the hypothesis that increases in the time and costs incurred in trade-related regulatory practices (measured using the TAB data) are negatively associated with fertilizer imports. A similar approach is used to test that more stringent

[41] These statistics are based on data for 2018 but are fairly similar to the pooled sample (2014-2018) because the indicators do not vary much over time (see Table 2A.7, Appendix 2A).

regulations on the fertilizer sector (measured using the EBA data) are negatively associated with fertilizer imports.

We estimate the following empirical model to test our hypothesis:

$$\ln Y_{it} = \beta_0 + \boldsymbol{M_{it}\beta_1} + \boldsymbol{Z_{it}\beta_2} + a_i + v_t + \varepsilon_{it} \quad (1)$$

Here, Y_{it} refers to the fertilizer imported by country *i* in year *t*; $\boldsymbol{M_{it}}$ (main variables of interest) is the vector of TAB variables on the time (in hours) and costs (as a percentage of GNI per capita) of documentary and border compliance for country *i* in year *t*; $\boldsymbol{Z_{it}}$ is the set of control variables for country *i* in year *t* that we discuss below in detail; a_i is the time-invariant unobserved heterogeneity; v_t are the year fixed effects; and ε_{it} is the idiosyncratic error term.

Although the notation in equation (1) suggests that the main variables of interest vary over time, in practice, we observe little temporal variation in them. For example, for the time and costs taken for documentary compliance respectively, only 9.9% and 1.6% of the within-country first differences were non-zero. Similarly, for time and cost of border compliance, only 12.3% and 7.5% respectively of the within country first-differences were non-zero (Table 2A.7, Appendix 2A). Given this general lack of within country over time variation, estimating equation (1) with country fixed effects may lead to high multicollinearity between the main variables of interest and the country fixed effects. Thus, we opt for a hybrid model following Allison (2009). The hybrid model allows us to control for some part of the country-level time-constant unobserved heterogeneity by including the country level time averages of the time-varying control variables but also allows us to include the largely time invariant main variables of interest.[42] We re-write the equation to be estimated following Schunck (2013) and estimate it via pooled ordinary least squares (POLS):

$$\ln Y_{it} = \alpha_0 + \boldsymbol{M_{it}\alpha_1} + \boldsymbol{Z_{it}\alpha_2} + \boldsymbol{\bar{Z}_i\alpha_3} + c_i + v_t + \varepsilon_{it} \quad (2)$$

Here, $\boldsymbol{\bar{Z}_i}$ represents the time average of all time-varying control variables and c_i is the remaining time invariant country level unobservables that have not been captured by $\boldsymbol{\bar{Z}_i}$. The estimates are consistent if all of the explanatory variables are uncorrelated with both the time-varying and time

[42] A simple method to test the relevance of the hybrid model versus a full correlated random effects (CRE) model is to compare the Wald statistics of both models (i.e., models with time averages of only time varying variables vs. model with time averages of all variables included in an analysis). The model with high statistical significance as indicated by a larger value of the Wald statistic is preferable. The Wald statistics of the hybrid and full CRE models for the analysis of the TAB data are 22.53 and 20.30, respectively (p<0.01 in both cases). Similarly, the Wald statistic of the hybrid and full CRE models in the model with TAB data and EBA data were 14.94 and 13.21. This indicates that the overall statistical significance of the hybrid model is slightly higher and thus it is preferred.

invariant unobservables, i.e., $E[\boldsymbol{x_{it}}'\varepsilon_{it}]$= 0 and $E[\boldsymbol{x_{it}}'c_i]$=0, where $\boldsymbol{x_{it}}$ is the vector of all time-varying and time invariant explanatory variables (Wooldridge, 2010). Standard errors are clustered by country.

The choice of control variables, $\boldsymbol{Z_{it}}$, is governed by our expectation of potential confounders that may be correlated with the main variables of interest as well as with fertilizer imports. We know from the trade literature that the size of an economy and the presence of a large domestic market are important determinants of volume of trade. Thus, we include the GDP (in constant 2010 USD), the population of the country, and their time averages to control for these factors.[43] The importance of agriculture in an economy and the performance of the agricultural sector may also be correlated with fertilizer imports as well as the main variables of interest (particularly those specific to the fertilizer sector). We therefore include among the control variables the agricultural GDP as a percentage of a country's total GDP, the hectares of crop area harvested (as a proxy for land under cultivation), the percentage of the total population that is rural, and annual rainfall (mm).

Another time-varying unobservable that could potentially be correlated with the GDP and agricultural GDP as well as fertilizer imports is a sudden change in the macroeconomy or political economy of a nation, such as a war or regime change. It is very difficult to assess the direction of the bias arising out of such changes without knowing the nature of the political or other sudden change. Nevertheless, such changes in the macroeconomy or political economy are rare and, moreover, the economic conditions of a country are not likely to change significantly in the period of just five years due to such changes. Additionally, war-stricken countries (e.g., Eritrea, Syria, and Yemen) are excluded from our analytical sample due to lack of data. Thus, we believe these concerns to be minimal in this study.

The measures of the time and costs of regulatory practices related to international trade (obtained from the TAB data) are not likely to be influenced by unobservables that explain fertilizer imports unless fertilizer imports comprise a large fraction of the country's total import bundle.[44] However, the fertilizer specific regulations (obtained from the EBA data) are likely to

[43]These variables have been widely used to control for country size in the trade literature. See Tinbergen (1962) for the pioneering work in this field; UNCTAD (2012) for a practical guidance on trade models; and Kabir, Salim, and Al-Mawali, (2017) for a more recent survey of literature.

[44] The average share of the value of fertilizer imports in the value of total imports (for a sample of 123 countries) was only 3.2% for 2018 and the median share that year was only 0.2%. These 123 countries were part of our analytical

be correlated with unobservables that affect fertilizer imports. The fertilizer sector of several developing countries is marked by heavy government intervention (Hernandez and Torero, 2018), making it very likely that there are unobservables that affect both fertilizer-specific regulations (measured using the EBA data) and fertilizer imports. In such countries, government-sponsored fertilizer subsidy programs may lead to large volumes of fertilizers being imported despite regulations that are not generally conducive to private sector imports, thus leading to estimates that are biased toward zero (i.e., less negative effects of stringent regulations on fertilizer imports). We are unable to control for these unobservables in our analysis but are mindful of this caveat when interpreting the results.

Another major confounding factor is the domestic prices of fertilizer products. Annual fluctuations in the international fertilizer prices should be captured by the time fixed effects but due to a lack of country level data on fertilizer product prices, we are unable to capture the spatial differences over time in fertilizer prices. Countries with higher fertilizer prices are also likely to have lower fertilizer quantities demanded. On the other hand, the relationship between stringent fertilizer regulations as measured through the EBA and fertilizer prices is likely to be positive (i.e., fertilizers prices are likely to be higher when there are more regulations on fertilizers). Thus, overall, the direction of bias is expected to be negative and the estimates of the effects of the fertilizer-specific regulations on fertilizer imports are likely to be more negative than their true values. We keep this caveat in mind when interpreting our results. However, it is worth noting that even these biased results will represent the effect of a fertilizer regulation on fertilizer imports (though we cannot distinguish whether this effect arises directly on the fertilizer imports or indirectly through the impact of the fertilizer regulation on fertilizer prices). Apart from fertilizer prices, spatial and temporal variation in prices of agricultural goods might also affect the demand for fertilizer within a country, but they are unlikely to be correlated with the fertilizer sector regulations (after controlling for other explanatory variables).

There is some cause for concern when it comes to the time invariant unobservables that cannot be captured by the hybrid panel approach we have adopted here. A country's general openness to trade and effective governance could be correlated with lower time and costs of documentary and border compliance as well as with its volume of fertilizer imports. Since larger

sample and are the countries for which data on the values of both total imports and fertilizer imports were available from the UN COMTRADE.

economies are more likely to be open to trade and have better governance, the GDP variable and time averages of GDP could in part control for this. Additionally, we include indicators for Governance Effectiveness and Control of Corruption from the Worldwide Governance Indicators (WGI) in our control variables. (See Table 1 for details.) Finally, geographical and political proximity of a nation with a large trading partner could potentially be correlated with lower time and costs of documentary and border compliance. We include a dummy variable for countries that are landlocked to control for some of the geographical differences among countries. However, there is still a possibility that our estimates are biased and overestimate the true effects of regulations on fertilizer imports. For example, South Africa possesses a vast coastline and is geographically and politically (through colonial ties) placed to be able to trade with a large number of countries. It is likely that international trade related regulations are relatively less stringent in South Africa to take advantage of its position and the country also imports large amounts of fertilizers to then export to other countries.

Several countries in our analysis also produce some quantities of fertilizer for domestic consumption. It is likely that fertilizer-specific regulations are correlated with domestic decisions on the amount of fertilizer to be produced domestically. This can bias our results. Thus, we include the volume of fertilizer produced in the country as another control variable.

2.4.2 Robustness Checks

We chose to use the information on rural share of the population to proxy for the dependence of the country on agriculture because these data are available for all countries in the sample. However, it is likely that not all of the rural population depends on agriculture and if the difference is large, this variable may not adequately capture the extent of a country's agricultural orientation. Similarly, the harvested area of main crops may be quite different from the total land that was put under cultivation if, due to droughts, floods or other natural causes, large parts of cultivated land were unharvested. Thus, we conduct robustness checks by replacing the rural share of the population and the area harvested with the percentage of the population dependent on agriculture and area under cultivation, respectively. However, due to fewer number of observations the analytical sample reduces to 745 and 740 respectively when using the agricultural population and the cropland variable respectively. Additionally, other agro-climatic characteristics such as soil characteristics (type, texture, soil organic matter, and pH levels, etc.), temperature, terrain and elevation, and geographical location may also influence the profitability and thus the use of fertilizers within the country. The values of these variables often vary considerably within countries and national-level aggregates are not readily available.[45] We do, however, conduct robustness checks in which we control for the latitude and longitude of each country to capture some geographic differences across countries.

Another issue relates to the relatively small number of countries that import substantial amounts of fertilizers to re-export them to other nations. Several upper middle-income countries are important international players in fertilizer trade (for example, Indonesia, Brazil, Peru, and South Africa are countries with ports and strong trade networks with neighboring low income and lower middle-income countries). Fertilizer import-conducive regulatory environments in these countries may make them desirable trading partners, thus increasing the volume of fertilizer imported by them. However, this is not a cause of concern because our estimation strategy still captures the effect of regulations on fertilizer imports. However, some concern may arise if the few countries that import large quantities of fertilizers to export them to other countries are influential outliers in our analysis (e.g., the top 3 exporters of fertilizers – Russia, China, and Canada – account for 40% of the fertilizer exported). Additionally, some countries that import fertilizers to export it to other nations and do not have a significant agricultural sector, may have a markedly different regulatory environment (such as relatively relaxed regulation of fertilizer due to potential health and environmental impacts)[46] The inclusion of a dummy variable for landlocked status helps control for part of this issue. As an additional robustness check, we conduct the analysis with net imports as the dependent variable. We only include countries that are net importers of fertilizers (i.e., imports are greater than exports).[47] This leads to a sample of 114 countries observed over 5 years (for a total of 570 observations) when considering the TAB data and 49 countries covering 2 years (for a total of 98 observations) when considering the EBA data.[48]

[45] For example, the Harmonized World Soil Database v 1.2, the most comprehensive data on global soil quality, is geocoded to locations that do not necessarily correspond with political boundaries.
[46] Some examples are Singapore, Madagascar, and Marshall Islands. These countries import and export fertilizers, but their net use of fertilizers was negative (calculated via the disappearance method as imports + production - exports).
[47] Including all countries (net importers and exporters) poses the challenge of converting the negative net import values to their logarithm terms. Excluding the net exporters of fertilizers solves this issue as well as helps focus on the countries that import fertilizers primarily for domestic consumption. We recognize, however, that focusing on countries with positive net imports may introduce sample selection issues.
[48] Only six of the EBA countries included in our analysis were net-exporters of fertilizers. These were Chile, Egypt, Georgia, Morocco, Nigeria, and Russia. See Table 2A.8 in Appendix A for details about countries excluded from the TAB analysis.

On the other hand, fertilizers imported by an intermediate country that are destined for another final country are unlikely to be affected by the fertilizer market specific regulations of the intermediate country. Thus, fertilizer specific regulations captured by the EBA data are unlikely to affect the fertilizer imports to a country if the imports are meant to be re-exported to another country. We consider this caveat when interpreting our results. The more general import regulations (captured by the TAB data) are still expected to influence such fertilizer imports through their effect on the efficiency with which products are moved through ports and borders.

Another important consideration is Regional Trade Agreements (RTAs), which are known to influence trade flows across international boundaries (Carrere, 2006). Countries that are part of an RTA likely share similar trade related regulations and may import larger amounts of fertilizers than countries that are not part of RTAs due to the benefits of collective bargaining that may come with being part of an RTA (Carrere, 2006; NML and AFAP, 2017). The World Trade Organization's database shows that there are currently 350 active RTAs that apply to trade of goods and services across countries (WTO, n.d., b). Including all these RTAs in the regression framework is infeasible. As an alternative we conduct a robustness check by including regional dummies for 17 major regions (to account for the potential RTAs that exist among the countries within each region). (See Table 2A.9 for the list of regions)

2.5 Results

Tables 2.2 and 2.3, respectively, summarize the main estimates obtained from the analysis using the TAB data only and the TAB data combined with the EBA data. We begin with a discussion of Table 2.2. We find that an hour increase in the time taken for documentary compliance is weakly associated with a 0.35%-0.45% reduction in the volume of fertilizer imported (Table 2.2, columns 1 and 2). However, this estimate does not remain statistically significant after controlling for measures of government effectiveness (columns 3 through 4). Further, the fertilizer import volume is positively and significantly associated with a higher ranking in the Control for Corruption index (where a higher ranking implies lower levels of corruption), which is one of the government effectiveness-related control variables (see Table 2B.1 in Appendix 2B for these results). It is possible that delays in completing the documentation for international trade are correlated with the prevalence of corrupt practices among customs and border agencies; this may explain why the time taken in documentary compliance is no longer significantly correlated with fertilizer imports after we control for levels of corruption in the model (Table 2.2, columns 3 through 4).

The results in Table 2.2 also suggest that an hour increase in the time taken for border compliance is associated with a 0.3%-0.6% decrease in the quantity of fertilizer imported, in line with our hypothesis; this result is robust to the inclusion of various sets of control variables, however the results are only weakly statistically significant ($p<0.1$) when controlling for the full set of variables. A 0.3% reduction in quantity of fertilizer imported is equivalent to a 13% reduction in volume of fertilizer imported given an increase of 43 hours in border compliance time (the difference between the median and the 75th percentile of this variable).

Table 2. 2: Estimates of the effects of the time and costs incurred in international trade on fertilizer imports, full sample pooled OLS (dependent variable: log of fertilizer imports (MT))

Variables	(1)	(2)	(3)	45)
Time taken in documentary compliance (hours)	-0.0045*	-0.0035*	-0.0022	-0.0026
	(0.00207)	(0.00163)	(0.00168)	(0.00165)
Time taken in border compliance (hours)	-0.0060***	-0.0040*	-0.0032*	-0.0032*
	(0.00166)	(0.00168)	(0.00159)	(0.00158)
Cost of documentary compliance	-0.00017	0.0034	0.0022	0.0024
(% of current GNI per capita)	(0.00277)	(0.00206)	(0.00233)	(0.00236)
Cost of border compliance	-0.00089	-0.0028	-0.0029	-0.0033
(% of current GNI per capita)	(0.00184)	(0.00168)	(0.00164)	(0.00166)
GDP and population	Yes	Yes	Yes	Yes
Measures of agricultural activity	No	Yes	Yes	Yes
Effectiveness of governance and landlocked status	No	No	Yes	Yes
Domestic production of fertilizer	No	No	No	Yes
Time averages	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Constant	-11.8***	-10.1***	-8.74***	-9.76***
	(1.717)	(2.618)	(2.439)	(2.462)
Observations	780	770	770	770
R-squared	0.755	0.791	0.797	0.809

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1. See Table 2B.1 in Appendix 2B for full results. Data on agricultural GDP are missing for Barbados and Libya for all years, thus reducing the analytical sample to 770 observations (154 countries X 5 years) for specifications (2) through (5). Control variables included in each of the categories above are as follows. GDP and population: log of current GDP and population. Measures of agricultural activity: Agricultural GDP as a percentage of total GDP, rural population as a percentage of total population, log of area of cropland harvested, and log of annual rainfall. Effectiveness of governance: percentile indices of Government Effectiveness and Control of Corruption. Indicator variable for landlocked status (=1 if landlocked). Domestic production of fertilizer: production of fertilizer (mn MT).

In contrast, the costs incurred in documentary and border compliance are not significantly related to fertilizer import volumes. Since the time and cost variables measure similar aspects of trade facilitation, they could be strongly correlated thus lead to multicollinearity. From Table 2A.10 in Appendix 2A, the correlation between the time and costs incurred in meeting border compliance is moderate to strong (correlation coefficient=0.62). Analysing the data with only cost variables (and omitting the time variables) reveals that a unit increase in the cost to meet border compliance is associated with 0.5%-0.6% reduction in the fertilizer imports, and the results remain robust to the different sets of control listed in Table 2.2 (see Table 2B.2 in Appendix 2B for these results). The cost of documentation is not statistically significantly related to fertilizer imports. Because the costs of documentary compliance and the costs of border compliance are also moderately to strongly correlated (0.63), we estimated a set of models that omits all time and cost variables except for the costs of documentary compliance. The estimates remain statistically insignificant for this variable (results not presented).

These results are robust to using alternative measures of agricultural activity and the inclusion of country level latitude and longitudinal data, as described in the robustness checks portion of the Methodology section. (See Tables 2B.3 and 2B.4 in Appendix 2B.) When including regional dummies to (partially) control for the effects of regional trade agreements, the coefficient on the time of border compliance does not remain statistically significant, while the coefficient on the cost of border compliance becomes significant at the 10% level (Table 2B.5, Appendix 2B.) Similarly, when conducting the analysis for the subset of net-importing countries with log of net-imports as the dependent variable, the coefficient of time taken for border compliance becomes insignificant while that of the cost incurred in border compliance becomes weakly significant ($p<0.1$) (Table 2B.6, Appendix 2B). Overall, the results seem to imply that it is the time and costs of border compliance that have more implications for fertilizer imports than the time and costs of documentary compliance. The regulations surrounding border compliance are probably of greater importance for fertilizers because the product is transported in bulky cargoes and is difficult to handle. Mishandling at ports and borders could lead to deterioration of quality and loss of quantity of the product (Luther, 2014).

The estimates from the regression analysis that includes the EBA-based fertilizer-specific regulation variables (together with the TAB-based, more general time and costs of documentary and border compliance variables) are presented in Table 2.3. Regulations on the import of fertilizers and sale of new fertilizers are not statistically significantly related to the volume of fertilizer imported. In addition, the time and costs incurred in international trade are not statistically significantly related to the volume of fertilizer imported when we limit the analysis to the EBA countries. The lack of statistical significance of both of these sets of variables (fertilizer-specific and time and costs of border/documentary compliance) may be due to the low statistical power resulting from the reduction in the analytical sample (from 780 to 118) when we include the EBA-based variables. The lack of significance of the EBA data could also be due to the effect of confounding factors that affect both fertilizer imports and fertilizer regulatory practices. Particularly, as discussed in the Methodology section, heavy intervention by governments in the fertilizer sector of developing countries may lead to increased fertilizer imports (directly or indirectly facilitated by the government) without any change in fertilizer specific regulations. The lack of significance of the EBA-based variables may also be related to the fact that fertilizer imports that are re-exported to other countries are unlikely to be affected by the intermediate trading partner's fertilizer-specific regulations.[49] Finally, the lack of significant effects of the EBA data may be reflective of the variables truly not being significantly related to fertilizer imports among the EBA countries. The next section further addresses this issue.

[49] The analysis of net-imports as the dependent variable with the EBA data indicated no significant effect of any of the variables of interest on the outcome variable (results available upon request).

Table 2. 3: Estimates of the effects of fertilizer-specific regulations on fertilizer imports, pooled OLS of EBA countries (dependent variable: log of fertilizer imports (MT))

Variables		(1)	(2)	(3)	(4)	(5)
Must private entities obtain an import permit to import fertilizer products? (Base: No permit required)	Yes, a blank permit with no restriction on volume purchased or number of shipments	-0.27	-0.28	-0.16	-0.27	-0.48
		(0.417)	(0.416)	(0.426)	(0.500)	(0.500)
	Yes, a permit is required per shipment, or restrictions exist on volume imported	0.15	0.16	-0.055	-0.22	-0.39
		(0.294)	(0.290)	(0.288)	(0.311)	(0.311)
Must private entities register a new fertilizer in order to sell it in country? (Base= No registration needed)	Yes, but registration need not be renewed periodically	0.51	0.49	0.46	0.47	0.57
		(0.395)	(0.420)	(0.517)	(0.506)	(0.542)
	Yes, registration is time-limited and needs to be renewed periodically	0.28	0.18	0.23	0.27	0.33
		(0.336)	(0.330)	(0.379)	(0.374)	(0.370)
Time taken in documentary compliance (hours)			-0.0036	-0.00086	-0.00063	-0.0021
			(0.00357)	(0.00253)	(0.00265)	(0.00292)
Time taken in border compliance (hours)			0.00074	-0.00023	-0.0011	-0.00057
			(0.00289)	(0.00286)	(0.00306)	(0.00325)
Cost of documentary compliance (% of current GNI per capita)			0.0018	0.0017	0.0014	0.0024
			(0.00305)	(0.00265)	(0.00308)	(0.00325)
Cost of border compliance (% of current GNI per capita)			-0.0092	-0.0082	-0.0074	-0.0092
			(0.00659)	(0.00667)	(0.00748)	(0.00818)
GDP and population		Yes	Yes	Yes	Yes	Yes
Measures of agricultural activity		No	No	Yes	Yes	Yes
Effectiveness of governance and landlocked status		No	No	No	Yes	Yes
Domestic production of fertilizer		No	No	No	No	Yes
Time averages		Yes	Yes	Yes	Yes	Yes
Time fixed effects		Yes	Yes	Yes	Yes	Yes
Constant		-6.47**	-5.03*	-5.04	-6.91	-6.51
		(2.415)	(2.444)	(2.982)	(4.414)	(4.569)

Table 2. 3 (cont'd)

Observations	118	118	118	118	118
R-squared	0.573	0.598	0.644	0.657	0.672

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1. See Table 2B.7 in Appendix 2B for full results. Control variables included in each of the categories above are as follows. GDP and population: log of current GDP and population. Measures of agricultural activity: Agricultural GDP as a percentage of total GDP, rural population as a percentage of total population, log of area of cropland harvested, and log of annual rainfall. Effectiveness of governance: percentile indices of Government Effectiveness and Control of Corruption. Indicator variable for landlocked status (=1 if landlocked). Domestic production of fertilizer: production of fertilizer (mn MT).

2.6 Further Analysis and Discussion of Rival Hypotheses

2.6.1 Further analysis to explore potential reasons for lack of significant results when analysing EBA data

The change in significance of the coefficients of regulatory practices when we introduce the EBA data may be driven by several factors. It could be that there are concerns of multicollinearity between the TAB- and the EBA-based regulatory variables. However, the correlation matrix presented in Table 2A.10 of Appendix 2A reveals that the correlations are not very strong (<0.30 in absolute value). Further the results obtained when using only EBA data (Table 2.3, col (1)) are also found to be insignificant.

We conduct a similar analysis on the sample of EBA countries but using only the TAB variables (and controls). The results remain statistically insignificant (Table 2B.8, Appendix 2B). These results imply that the change in significance is possibly driven by the reduction of the sample to the EBA countries only. However, since the EBA data are observed only for the years 2017 and 2018, it is possible that there is something peculiar about these years that could be driving the results. If this is true, then the coefficients from the analysis of TAB indicators for all years but restricted to the sample of the EBA countries should be robust to those found in Table 2.2. We conduct this analysis and find the coefficients to be insignificant (Table 2B.9, Appendix 2B) strengthening our belief that the EBA countries may be inherently different than the rest of the sample in a way that affects our results.[50] Finally, we conduct an analysis including the TAB- and EBA-based variables data but without the time averages. Some of our estimates change significantly in this case (Table 2B.11, Appendix 2B). The requirement of registering a new fertilizer product but without any time restrictions is found to be positively and significantly related to increased fertilizer imports as compared to the base case of no registration requirements whatsoever. This effect, however, does not remain statistically significant after controlling for the landlocked status of a country. In contrast, the costs of meeting border compliance are negatively and significantly related to fertilizer imports and this result is robust across all specifications. These results provide considerable reason to believe that unobservable country-specific characteristics may be affecting our results when we focus on the EBA countries.

[50] On the other hand, the estimates from an analysis of all countries (N=156) but restricted to 2017 and 2018 are similar to that of Table 2.2 (Table 2B.10, Appendix 2B).

Due to the EBA's focus on agriculture, countries in our EBA analytical sample are more likely to be low or lower middle income countries (60%) as compared to countries in our full analytical sample (36% low or lower middle income). It is likely that unobservables that are related to the income status of countries affect the regulatory environment as well as fertilizer imports. Freund and Rocha (2011) also found the TAB indicators to be insignificant in explaining the flow of exports amongst countries in SSA (though in a cross-sectional analysis and thus without accounting for time invariant unobserved heterogeneity). Some of this concern is addressed through the inclusion of the time averages of the GDP- and government effectiveness-related variables. To further explore the extent to which the results might differ by the income status of a country, we re-run the analysis using the TAB data separately for high and upper middle income countries vs. low and lower middle income countries. We also conduct a similar analysis with both the TAB and EBA data, although with severe a loss of statistical power due to the small sample size. The results reveal that the coefficient on time for border compliance is negative and highly significant ($p<0.001$) in case of high and upper middle income countries (Table 2B.12, Appendix 2B); the time of documentary compliance and the costs of documentary and border compliance are not significantly correlated with fertilizer imports. These results are consistent with our main results in Table 2.2. However, the time for border compliance ceases to be statistically significant (and the other TAB-related regulatory variables remain insignificant) when we reconduct the analysis focusing only on low and lower middle income countries (Table 2B.13, Appendix 2B).

Similarly, in the case of the EBA-based regulatory variables, an analysis of the high and upper middle income countries (consisting of only 48 observations – 24 countries over two years) yielded some statistically significant results for both the TAB and EBA-based regulatory variables (Table 2B.14, Appendix 2B). The requirement of a permit to import fertilizers without any volume restrictions (relative to no import permit requirement at all) is positively associated with fertilizer imports in some specifications, although the effect does not remain significant after controlling for landlocked status. Among the TAB-based variables, the time incurred in border compliance and the cost of documentary compliance are both negatively and significantly correlated with fertilizer imports. The same analysis for low income countries (consisting of only 70 observations – 35 countries over two years) yielded no statistically significant results for the TAB-based variables but suggests that requiring a permit to import fertilizers without any volume restrictions (relative to no import permit requirement at all) is negatively associated with fertilizer imports (Table

2B.15, Appendix 2B). This result is robust across the different specifications. However, given the very small sample sizes of the separate analyses of low/lower middle vs. high/upper middle EBA countries, we abstain from drawing strong conclusions based on these results except for acknowledging that the results may indeed be influenced by unobservables linked to the income status of the country.

2.6.2 Recent debate on relevance of index-based measures enabling environment for developing countries

One potential reason for the lack of significance of the TAB and EBA measures in case of low income countries could be that they are insufficient measures of enabling environment in developing country context. It is important to note that concerns have been raised recently about the use of index-based benchmarking measures of the enabling environment for developing countries, such as the Doing Business and Enabling the Business of Agriculture datasets (USAID, 2020a). It is argued that while they provide valuable information on markets that are comparable across time and countries, they may miss important aspects of markets in the developing world since they are primarily concerned with formal rules that govern market performance, such as laws, regulations, and institutions. However, where enforcement of such rules is weak, as may be the case in many developing countries, they may be insufficient measures of the market environment. Moreover, the presence of informal or personal forms of market rules is more common in many developing countries and their influence may override those of the formal ones (USAID, 2019). Working through not only formal rules and institutions but also through informal rules and institutions that better acknowledge the socio-cultural norms and contexts of local legal practices is considered increasingly important in improving market performance in developing countries (McCormack, 2018; USAID 2020b).[51]

2.7 Conclusions and Policy implications

In this paper, we explored whether changes in the regulations pertaining to international trade and domestic fertilizer markets affect fertilizer imports. We focus on fertilizer imports because many countries across the globe, and particularly developing countries, depend on imports to meet their domestic fertilizer needs. We tested the hypothesis that more stringent or onerous regulations on international trade (measured as the time and costs of border and documentary compliance) and

[51] The USAID's Inclusive Entrepreneurial Market System (IEMS) is one such initiative.

on the domestic fertilizer market (measured through indicators of rules about fertilizer import permits and registration of new fertilizer products) are correlated with lower fertilizer imports. We find weak evidence that increased time and/or costs needed to comply with border regulations (such as clearing customs and inspections) are associated with a decline in the volume of fertilizer imported. It is unclear whether the time of border compliance, the costs of border compliance, or both are equally important factors influencing fertilizer imports. This is because we are unable to disentangle the effects of the two explanatory variables because of their moderately high correlation. Border compliance is likely to be consequential to fertilizer imports due to the bulky nature of fertilizers and the need for proper handling at ports to avoid losses of quantity and quality of the product (Luther, 2014). We also find that the time needed to comply with import related documentary procedures is associated with lower fertilizer imports, but this effect does not remain statistically significant when we control for the prevalence of corrupt practices. The prevalence of corrupt practices could be correlated with delays in the documentation required for international trade and also negatively affects fertilizer imports.

On the other hand, the regulations on domestic fertilizer markets that we analyze are not significantly related to fertilizer imports. Potential reasons for this lack of significance (apart from the variables truly not being significantly related to fertilizer imports among the EBA countries) could be the small sample size and low statistical power in our analysis of the fertilizer-specific regulations. There is also concern that government-led import of fertilizers (which is common in some developing countries) could be confounding the effect of government regulations on total fertilizer imports by a country. We are unable to test this claim due to lack of comprehensive data on government-led fertilizer imports. Apart from this, we consider the possibility that lower income and higher income countries are different in their market responses to the regulations we measure. For low income and lower middle income countries, we find that neither the regulations governing international trade nor those specific to domestic fertilizer markets are significantly correlated with fertilizer imports. In contrast, for high income and upper middle income countries, some elements of both types of regulations are correlated with fertilizer imports. The time of documentary compliance is found to be negatively correlated with fertilizer imports for these countries. In contrast, the requirement of obtaining a permit to import fertilizer, though without any restriction on volume purchased or number of shipments, was found to be positively associated with fertilizer imports. It is possible that in lower income countries, poor enforcement of formal laws and a greater importance of informal laws might override the effects of formal international trade-related and fertilizer-specific regulations on fertilizer imports (USAID, 2019; USAID, 2020a.)

Our results are also likely to be important for low income countries that import fertilizers from upper middle income countries. This is because several upper middle income countries in our analysis are important trading partners of low income countries due to their geographic or political proximity (e.g., Indonesia, Brazil, Peru, and South Africa), and import fertilizers for re-export to other low income developing countries. Thus, import conducive regulations in an upper middle income country are likely to increase the flow of fertilizer imports meant to be re-exported to other countries. This is, however, not true for fertilizer specific regulations since they only affect the fertilizer imports of the country of final destination.

The results of this study are timely because the WTO recently passed the Trade Facilitation Agreement (TFA) with the goal of simplifying the process of trade among countries. A key feature of the TFA is that developing countries who are signatories to the agreement can choose their own timeline for implementation of the agreement and will be assisted through a Trade Facilitation Agreement Facility, which will provide technical and financial assistance in assessing their needs and identifying and implementing good practices. The commencement of the African Continental Free Trade Agreement (AfCFTA) in January 2021 is also an opportunity for developing countries in SSA, where fertilizer consumption remains among the lowest in the world. The AfCFTA could help improve the environment for trade of fertilizers among member countries, and between member countries and the rest of the world.

APPENDICES

APPENDIX 2A: Summary Statistics

Table 2A. 1: Summary statistics of variables used in the analysis (pooled sample)

Panel A: Continuous variables								
	N	Mean	SD	Min	p25	p50	p75	Max
Fertilizer imports, '000 MT	780	610.19	1654.97	0.00	18.46	102.69	460.80	14,280
Fertilizer exports, '000 MT	780	624.43	2194.45	0.00	0.016	15.206	279.456	23,354
Fertilizer productions, '000 MT	780	1,323	5,555	0.00	0.00	0.00	557	65,079
Time taken in documentary compliance (hours)	780	60.74	70.63	0.50	3.00	36.00	96.00	546.43
Time taken in border compliance (hours)	780	71.17	83.51	0.00	6.00	53.33	96.00	588.00
Cost to import for documentary compliance (current USD)	780	154.72	191.90	0.00	40.00	90.00	189.00	1,025.00
Cost to import for border compliance (current USD)	780	428.79	410.58	0.00	135.90	353.57	597.63	3,039.0
Cost to import for documentary compliance (% of current GNI per capita)	780	12.04	38.24	0.00	0.20	1.20	8.70	394.23
Cost to import for border compliance (% of current GNI per capita)	780	22.62	60.01	0.00	0.91	5.33	19.69	690.68
Area harvested for all crops listed by FAOSTAT, '000 ha	780	8,843	24,766	0.64	288	1,741	6,572	2,05,065
Cropland, '000 ha [a]	775	9,775	24,687	0.66	459	2,245	7,910	169,463
Arable land, '000 ha	780	8,707	23,052	0.15	398	1,800	6,020	157,736
GDP at constant 2010 mn USD	780	490,237	1,703,161	160	13,424	48,515	265.089	17,960,940
Ag GDP (% of GDP) [b]	770	9.84	9.26	0.03	2.27	6.57	14.77	38.52
Population, '000	780	46,001	156,714	51	2,948	10,109	34,895	1,392,730
Rural population (% of total)	780	40.46	22.63	0.00	21.74	38.72	58.20	88.22
Population dependent on ag (% of total) [c]	755	23.53	21.49	0.06	4.84	17.58	35.18	86.31

Table 2A. 1 (cont'd)

Government Effectiveness, Percentile Rank (0-100)	780	52.73	27.08	1.44	29.81	53.13	74.52	100.00
Regulatory Quality, Percentile Rank (0-100)	780	52.87	27.08	0.48	31.25	52.88	74.04	100.00
Control of Corruption, Percentile Rank (0-100)	780	50.19	28.06	0.96	25.96	48.56	73.32	100.00
Latitude [d]	775	20.59	24.75	-40.90	4.53	21.51	41.38	64.96
Longitude [d]	775	16.99	63.69	-175.19	-7.09	20.17	47.58	179.41

Panel B: Categorical and binary variables

Variable		No.	%
Must private entities obtain an import permit to import fertilizer products? (N=118)	No	42	35.59
	Yes, no restrictions on volume imported or number of shipments	23	19.49
	Yes, and restrictions on volume or number of shipments	53	44.92
Must private entities register a new fertilizer product to sell it in the country? (N=118)	No	29	24.58
	Yes, but registration not time limited	28	23.73
	Yes, time limited restriction	61	51.69
Country is landlocked=1 (N=780)		160	20.51

Notes: MT = metric tons. GNI= Gross National Income. [a] Data are missing for Angola. [b] Data are missing for Barbados and Libya. [c] Data are missing for Antigua and Barbuda, Dominica, Marshall Islands, Saint Kitts and Nevis, Seychelles. [d] Data are missing for Sudan.

Table 2A. 2: Countries/territories included in the full sample

Panel A: Countries included in both the TAB and EBA data and for which fertilizer import data are available (N=59)
Armenia, Bangladesh, Benin, Bolivia (Plurinational State of), Bosnia and Herzegovina, Burkina Faso, Burundi, Cambodia, Cameroon, Chile, Colombia, Cote d'Ivoire, Denmark, Egypt, Ethiopia, Georgia, Ghana, Greece, Guatemala, India, Italy, Jordan, Kazakhstan, Kenya, Kyrgyzstan, Malawi, Malaysia, Mali, Mexico, Morocco, Mozambique, Myanmar, Nepal, Netherlands, Nicaragua, Niger, Nigeria, Peru, Philippines, Poland, Republic of Korea, Romania, Russian Federation, Rwanda, Senegal, Serbia, Spain, Sri Lanka, Sudan, Tajikistan, Thailand, Turkey, Uganda, Ukraine, United Republic of Tanzania, Uruguay, Viet Nam, Zambia, Zimbabwe
Panel B: Countries included in the TAB data only and for which fertilizer import data are available (N=97)
Afghanistan, Albania, Algeria, Angola, Antigua and Barbuda, Argentina, Australia, Austria, Azerbaijan, Bahamas, Bahrain, Barbados, Belarus, Belgium, Belize, Bhutan, Botswana, Brazil, Brunei Darussalam, Bulgaria, Canada, Central African Republic, China, Congo, Costa Rica, Croatia, Cyprus, Czechia, Democratic Republic of the Congo, Dominica, Dominican Republic, Ecuador, El Salvador,, Estonia, Fiji, Finland, France, Gabon, Gambia, Germany, Guinea, Guyana, Honduras, Hungary, Iceland, Indonesia, Iran (Islamic Republic of), Iraq, Ireland, Israel, Jamaica, Japan, Kuwait, Latvia, Lebanon, Libya, Lithuania, Luxembourg, Madagascar, Maldives, Malta, Marshall Islands, Mauritius, Mongolia, Montenegro, Namibia, New Zealand, North Macedonia, Norway, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Portugal, Qatar, Republic of Moldova, Saint Kitts and Nevis, Saint, Lucia, Samoa, Saudi Arabia, Seychelles, Singapore, Slovakia, Slovenia, South Africa, Suriname, Sweden, Switzerland, Togo, Tonga, Trinidad and Tobago, Tunisia, United Arab Emirates, United Kingdom of Great Britain and Northern Ireland, United States of America, Uzbekistan

Table 2A. 3: Countries/territories excluded from the study's analytical sample

Panel A: Countries not included in the TAB data (N=6)
Bermuda, Cook Islands, Cuba, French Polynesia, Nauru, New Calendonia
Panel B: Countries included in the TAB data but lacking data on fertilizer imports (N=26)
Cabo Verde, Chad, Comoros, Djibouti, Equatorial Guinea, Eswatini, Grenanda, Guinea-Bissau, Haiti, Kiribati, Lao PDR, Lesotho, Liberia, Liechtenstein, Mauritiana, Micronesia, Fed. Sts, Palau, Puerto Rico, San Marino, Sierra Leone, Solomon Islands, Somalia, South Sudan, St. Vincent & the Grenadines, São Tomé and Príncipe, Vanuatu
Panel C: Countries included in the TAB data but lacking data on important controls (N=6)
Hong Kong, Taiwan, Venezuela, Syrian Arab Republic, Yemen, Eritrea

Table 2A. 4: Descriptive statistics for fertilizer trade and production

		Imports	Exports*	Production	Net imports (Import-Export)
Statistics for 2018					
No. of countries with non-zero values		156	125	75	122
Summary statistics for countries with non-zero values (1000 MT):	Average	630.51	771.53	2,705.33	-5.40
	Median	108.79	99.18	610.0	54.48
	SD	1,778.38	2,311.98	7,081.02	2,764.43
	Min	0.0025	.0030	0.264	-16,258.49
	Max	14,280.74	16,396.30	52,041.25	14,109.62
Statistics for the pooled sample (2014-2018)					
Summary statistics for countries with non-zero values (1000 MT):	Average	610.19	761.02	2,781.80	-14.24
	Median	102.69	66.03	623.55	31.99
	SD	1,654.97	2,401.37	7,804.91	2,459.62
	Min	0.0010	0.0013	0.1112	-23,039.10
	Max	14,280.74	234,000.00	65,079.58	14,107.34

Notes: All 156 countries imported some amount of fertilizer in all years in the sample. The number of countries exporting and producing non-zero values of fertilizers for the pooled sample of 2014-2018 ranged from 125-133 and 74-75, respectively. The number of countries with a positive net import value during the 2014-18 period ranged from 119-123. * Observations with less that 1 MT of exports were converted to zero.

Table 2A. 5: Must private entities obtain a permit to import fertilizers (EBA, 2018)

	High Income	Upper middle income	Lower middle income	Low income
No	7 (77.8%)	8 (53.3%)	6 (24.0%)	0 (0.0%)
Yes, but no restriction on the number of shipments or volume of fertilizer transacted	1 (11.1%)	3 (20.0%)	4 (16.0%)	3 (30.0%)
Yes, restrictions either on the number of shipments or on the volume of fertilizer transacted	1 (11.1%)	4 (26.7%)	15 (60.0%)	7 (70.0%)
N	9	15	25	10

Table 2A. 6: Must private entities register a new fertilizer in in order to sell it in the country? (EBA, 2018)

	High Income	Upper middle income	Lower middle income	Low income
No	1 (11.1%)	2 (13.3%)	7 (28.0%)	4 (40.0%)
Yes, registration is required once when a new product is introduced	2 (22.2%)	3 (20.0%)	5 (20.0%)	3 (30.0%)
Yes, registration is required and must be periodically renewed.	6 (66.7%)	10 (66.7%)	13 (5.2%)	3 (30.0%)
N	9	15	25	10

Table 2A. 7: No. of observations with non-zero within-country first differences of variables of interest (2014-2018)

Variable	Time of documentary compliance	Cost of documentary compliance	Time of border compliance	Cost of border compliance
No. observations where first difference>0	62	10	77	44
As a % of the total country-year observations (N=624)	9.9	1.6	12.3	7.5

Note: The total number of country-year observations of first differences = 780-156=624

Table 2A. 8: Net-exporting countries/territories excluded from the analytical sample when focusing on net-importers only

Panel A: Countries that are net-exporters in all years (N=31)
Algeria, Bahrain, Belarus, Belgium, Canada, Chile, China, Croatia, Egypt, Georgia, Germany, Iran, Israel, Jordan, Kuwait, Lebanon, Libya, Lithuania, Morocco, Netherlands, Norway, Oman, Qatar, Russian Federation, Saudi Arabia, Singapore, Slovakia, Trinidad and Tobago, Tunisia, United Arab Emirates, Uzbekistan
Panel B: Countries that were net-exporters in atleast one but not all years (N=11)
Benin, Bolivia (Plurinational State of), Brunei Darussalam, Finland, Kazakhstan, Madagascar, Marshall Islands, Nigeria, Romania, Senegal, Ukraine

Table 2A. 9: Number of countries in the analytical sample by region

Region	No. of countries
Australia and New Zealand	2
Central Asia	4
Eastern Asia	4
Eastern Europe	10
Latin America and the Caribbean	28
Melanasia	2
Micronesia	1
North Africa	6
North America	2
Northern Europe	10
Polynesia	2
South East Asia	9
South Asia	9
Southern Europe	12
Sub-Saharan Africa	33
Western Asia	15
Western Europe	7
Total	156

Table 2A. 10: Correlation matrices of main explanatory variables

Panel A: TAB variables and analytical sample (N=780)

	Time taken in documentary compliance (hours)	Time taken in border compliance (hours)	Cost of documentary compliance (% of current GNI per capita)	Cost of border compliance (% of current GNI per capita)
Time taken in documentary compliance (hours)	1.00			
Time taken in border compliance (hours)	0.664	1.00		
Cost of documentary compliance (% of current GNI per capita)	0.456	0.366	1.00	
Cost of border compliance (% of current GNI per capita)	0.431	0.615	0.626	1.00

Panel B: TAB and EBA variables and analytical sample (N=118)

	Time taken in documentary compliance (hours)	Time taken in border compliance (hours)	Cost of documentary compliance (% of current GNI per capita)	Cost of border compliance (% of current GNI per capita)	Import permit requirement (=1)	New fertilizer product registration (=1)
Import permit requirement (=1)	0.244	0.297	0.192	0.2421	1.00	
New fertilizer product registration (=1)	-0.176	-0.159	-0.20	-0.293	0.026	1.00

APPENDIX 2B: Full Results

Table 2B. 1: Estimates of the effects of changes in the time and costs incurred in international trade on fertilizer imports, full sample pooled OLS (dependent variable: log of fertilizer imports (MT))

	(1)	(2)	(3)	(4)
Time taken in documentary compliance (hours)	-0.0045*	-0.0035*	-0.0022	-0.0026
	(0.00207)	(0.00163)	(0.00168)	(0.00165)
Time taken in border compliance (hours)	-0.0060***	-0.0040*	-0.0032*	-0.0032*
	(0.00166)	(0.00168)	(0.00159)	(0.00158)
Cost of documentary compliance (% of current GNI per capita)	-0.00017	0.0034	0.0022	0.0024
	(0.00277)	(0.00206)	(0.00233)	(0.00236)
Cost of border compliance (% of current GNI per capita)	-0.00089	-0.0028	-0.0029	-0.0033
	(0.00184)	(0.00168)	(0.00164)	(0.00166)
ln(GDP, constant 2010 USD)	1.30	1.59*	1.49*	1.53*
	(0.741)	(0.734)	(0.713)	(0.711)
ln(Population)	-0.99	0.19	0.67	0.55
	(1.356)	(1.266)	(1.297)	(1.321)
Ag GDP (% of total GDP)		-0.019	-0.017	-0.018
		(0.0260)	(0.0252)	(0.0253)
Rural population (% of total population)		0.16	0.14	0.13
		(0.0805)	(0.0797)	(0.0835)
ln(Annual rainfall, mm)		-0.15	-0.15	-0.15
		(0.148)	(0.149)	(0.148)
ln(Annual crop area harvested, ha)		-0.20	-0.21	-0.21
		(0.141)	(0.136)	(0.136)
Government Effectiveness, Percentile Rank (0-100)			0.0042	0.0039
			(0.00894)	(0.00892)
Control of Corruption, Percentile Rank (0-100)			0.014*	0.014*
			(0.00671)	(0.00673)
Country is landlocked=1			0.15	0.057
			(0.260)	(0.259)
Domestic production of fertilizer, mn tons				0.036
				(0.0344)
Time avg: ln(GDP, constant 2010 USD)	0.35**	0.30	0.057	0.064
	(0.105)	(0.189)	(0.217)	(0.214)
Time avg: ln(Population)	0.94***	0.46*	0.68**	0.74**
	(0.113)	(0.222)	(0.248)	(0.249)

Table 2B. 1 (cont'd)

Time avg: Ag GDP (% of total GDP)		-0.037	-0.040	-0.044
		(0.0291)	(0.0275)	(0.0274)
Time avg: Rural population (% of total population)		-0.0082	-0.010	-0.0080
		(0.00967)	(0.00855)	(0.00831)
Time avg: ln(Annual rainfall, mm)		0.18	0.19	0.17
		(0.104)	(0.103)	(0.102)
Time avg: ln(Annual crop area harvested, ha)		0.46***	0.47***	0.47***
		(0.0863)	(0.0876)	(0.0853)
Time avg: Government Effectiveness, Percentile Rank (0-100)			0.013	0.014
			(0.0201)	(0.0191)
Time avg: Control of Corruption, Percentile Rank (0-100)			0.0038	0.0040
			(0.0138)	(0.0128)
Time avg: Domestic production of fertilizer, mn tons				-0.061**
				(0.0230)
Year=2015	-0.047	-0.019	-0.026	-0.030
	(0.0613)	(0.0610)	(0.0610)	(0.0610)
Year=2016	0.012	0.059	0.049	0.042
	(0.0695)	(0.0698)	(0.0704)	(0.0710)
Year=2017	0.0080	0.078	0.072	0.061
	(0.109)	(0.110)	(0.109)	(0.109)
Year=2018	-0.082	0.039	0.031	0.017
	(0.112)	(0.107)	(0.106)	(0.106)
Constant	-11.8***	-10.1***	-8.74***	-9.76***
	(1.717)	(2.618)	(2.439)	(2.462)
Observations	780	770	770	770
R-squared	0.755	0.791	0.797	0.809

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1. Data on agricultural GDP are missing for Barbados and Libya for all years, thus reducing the analytical sample to 770 observations (154 countries).

Table 2B. 2: Estimates of the effects of changes in the costs incurred in international trade on fertilizer imports, full sample pooled OLS (dependent variable: log of fertilizer imports (MT))

	(1)	(2)	(3)	(4)
Cost of documentary compliance (% of current GNI per capita)	-0.00016	0.0036	0.0020	0.0021
	(0.00309)	(0.00214)	(0.00243)	(0.00254)
Cost of border compliance (% of current GNI per capita)	-0.0059*	-0.0061***	-0.0051**	-0.0055**
	(0.00233)	(0.00178)	(0.00159)	(0.00163)
ln(GDP, constant 2010 USD)	0.81	1.17	1.18	1.20
	(0.635)	(0.669)	(0.654)	(0.651)
ln(Population)	0.53	0.97	1.25	1.16
	(1.162)	(1.183)	(1.235)	(1.265)
Ag GDP (% of total GDP)		-0.018	-0.017	-0.018
		(0.0242)	(0.0240)	(0.0241)
Rural population (% of total population)		0.10	0.11	0.098
		(0.0730)	(0.0736)	(0.0776)
ln(Annual rainfall, mm)		-0.15	-0.15	-0.15
		(0.147)	(0.149)	(0.149)
ln(Annual crop area harvested, ha)		-0.23	-0.23	-0.23
		(0.134)	(0.132)	(0.132)
Government Effectiveness, Percentile Rank (0-100)			0.0057	0.0056
			(0.00856)	(0.00856)
Control of Corruption, Percentile Rank (0-100)			0.013*	0.013*
			(0.00623)	(0.00624)
Country is landlocked=1			0.26	0.18
			(0.271)	(0.270)
Domestic production of fertilizer, mn tons				0.031
				(0.0353)
Time avg: ln(GDP, constant 2010 USD)	0.53***	0.46*	0.047	0.051
	(0.101)	(0.190)	(0.215)	(0.212)
Time avg: ln(Population)	0.70***	0.16	0.59*	0.65**
	(0.108)	(0.193)	(0.239)	(0.238)
Time avg: Ag GDP (% of total GDP)		-0.040	-0.042	-0.046
		(0.0311)	(0.0280)	(0.0279)
Time avg: Rural population (% of total population)		-0.0069	-0.011	-0.0085
		(0.0101)	(0.00878)	(0.00853)
Time avg: ln(Annual rainfall, mm)		0.23*	0.22*	0.20

Table 2B. 2 (cont'd)

		(0.113)	(0.108)	(0.108)
Time avg: ln(Annual crop area harvested, ha)		0.54***	0.53***	0.54***
		(0.0860)	(0.0843)	(0.0814)
Time avg: Government Effectiveness, Percentile Rank (0-100)			0.020	0.022
			(0.0195)	(0.0185)
Time avg: Control of Corruption, Percentile Rank (0-100)			0.0034	0.0037
			(0.0139)	(0.0130)
Time avg: Domestic production of fertilizer, mn tons				-0.060**
				(0.0224)
Year=2015	-0.037	-0.020	-0.027	-0.030
	(0.0548)	(0.0567)	(0.0578)	(0.0579)
Year=2016	0.028	0.055	0.044	0.040
	(0.0650)	(0.0668)	(0.0678)	(0.0685)
Year=2017	0.044	0.079	0.071	0.064
	(0.104)	(0.105)	(0.105)	(0.105)
Year=2018	-0.0024	0.062	0.048	0.038
	(0.104)	(0.102)	(0.101)	(0.102)
Constant	-13.0***	-11.3***	-8.75***	-9.76***
	(1.768)	(2.744)	(2.418)	(2.440)
Observations	780	770	770	770
R-squared	0.717	0.774	0.790	0.801

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1. Data on agricultural GDP are missing for Barbados and Libya for all years, thus reducing the analytical sample to 770 observations (154 countries).

Table 2B. 3: Estimates of the effects of changes in the time and costs incurred in international trade on fertilizer imports – using alternative measures of dependence on agriculture as controls, full sample pooled OLS (dependent variable: log of fertilizer imports (MT))

	(1)	(2)	(3)	(4)	(5)	(6)
Time taken in documentary compliance (hours)	-0.0033*	-0.0024	-0.0027	-0.0035*	-0.0022	-0.0026
	(0.00164)	(0.00171)	(0.00168)	(0.00155)	(0.00160)	(0.00156)
Time taken in border compliance (hours)	-0.0027	-0.0026*	-0.0026*	-0.0040*	-0.0033*	-0.0033*
	(0.00170)	(0.00171)	(0.00172)	(0.00168)	(0.00161)	(0.00160)
Cost of documentary compliance (% of current GNI per capita)	0.0037	0.0027	0.0029	0.0029	0.0017	0.0019
	(0.00199)	(0.00243)	(0.00246)	(0.00225)	(0.00260)	(0.00265)
Cost of border compliance (% of current GNI per capita)	-0.0032	-0.0033	-0.0036*	-0.0030	-0.0031	-0.0035*
	(0.00171)	(0.00180)	(0.00182)	(0.00176)	(0.00174)	(0.00177)
ln(GDP, constant 2010 USD)	1.14	1.08	1.19	1.47	1.39	1.44
	(0.755)	(0.749)	(0.751)	(0.756)	(0.737)	(0.734)
ln(Population)	-0.61	-0.26	-0.39	0.28	0.73	0.61
	(1.251)	(1.289)	(1.297)	(1.280)	(1.323)	(1.348)
Ag GDP (% of total GDP)	-0.029	-0.027	-0.029	-0.019	-0.018	-0.019
	(0.0263)	(0.0261)	(0.0262)	(0.0265)	(0.0259)	(0.0259)
Rural population (% of total population)				0.15	0.13	0.13
				(0.0786)	(0.0779)	(0.0817)
Population dependent on Ag (% of total)	0.015	0.011	0.012			
	(0.0347)	(0.0334)	(0.0341)			
ln(Annual rainfall, mm)	-0.13	-0.13	-0.13	-0.15	-0.15	-0.15
	(0.153)	(0.154)	(0.153)	(0.146)	(0.147)	(0.146)
ln(Annual crop area harvested, ha)	-0.17	-0.18	-0.18			
	(0.119)	(0.117)	(0.117)			
ln(Annual cropland, ha)				-0.35	-0.36	-0.36
				(0.236)	(0.250)	(0.244)
Government Effectiveness, Percentile Rank (0-100)		0.00046	0.000020		0.0043	0.0040
		(0.00795)	(0.00797)		(0.00895)	(0.00892)
Control of Corruption, Percentile Rank (0-100)		0.013*	0.013*		0.015*	0.015*
		(0.00629)	(0.00633)		(0.00685)	(0.00688)
Country is landlocked=1		0.15	0.100		0.15	0.059
		(0.257)	(0.255)		(0.263)	(0.261)
Domestic production of fertilizer, mn tons			0.058*			0.036
			(0.0263)			(0.0339)
Time avg: ln(GDP, constant 2010 USD)	0.28	0.14	0.13	0.25	0.015	0.022
	(0.175)	(0.199)	(0.197)	(0.187)	(0.220)	(0.217)
Time avg: ln(Population)	0.38	0.57*	0.65**	0.57**	0.79**	0.85***
	(0.232)	(0.222)	(0.226)	(0.212)	(0.240)	(0.241)
Time avg: Ag GDP (% of total GDP)	-0.031	-0.039	-0.041	-0.037	-0.041	-0.045

Table 2B. 3 (cont'd)

	(0.0303)	(0.0296)	(0.0296)	(0.0285)	(0.0266)	(0.0263)
Time avg: Rural population (% of total population)				-0.0079	-0.0094	-0.0072
				(0.00957)	(0.00853)	(0.00825)
Time avg: Population dependent on Ag (% of total)	-0.014	-0.015	-0.015			
	(0.0116)	(0.0119)	(0.0118)			
Time avg: ln(Annual rainfall, mm)	0.25*	0.27**	0.25**	0.24*	0.25*	0.23*
	(0.0977)	(0.0944)	(0.0940)	(0.104)	(0.103)	(0.101)
Time avg: ln(Annual crop area harvested, ha)	0.46***	0.45***	0.46***			
	(0.0858)	(0.0909)	(0.0886)			
Time avg: ln(Annual cropland, ha)				0.44***	0.45***	0.46***
				(0.0791)	(0.0793)	(0.0750)
Time avg: Government Effectiveness, Percentile Rank (0-100)		-0.014	-0.011		0.010	0.011
		(0.0151)	(0.0146)		(0.0201)	(0.0191)
Time avg: Control of Corruption, Percentile Rank (0-100)		0.022*	0.021*		0.0057	0.0059
		(0.0101)	(0.00949)		(0.0138)	(0.0128)
Time avg: Domestic production of fertilizer, mn tons			-0.048*			-0.061*
			(0.0208)			(0.0246)
Year=2015	-0.037	-0.040	-0.044	-0.017	-0.024	-0.028
	(0.0596)	(0.0594)	(0.0593)	(0.0616)	(0.0617)	(0.0617)
Year=2016	0.017	0.013	0.0060	0.059	0.050	0.042
	(0.0667)	(0.0671)	(0.0668)	(0.0698)	(0.0705)	(0.0709)
Year=2017	0.050	0.048	0.038	0.077	0.070	0.060
	(0.105)	(0.105)	(0.104)	(0.111)	(0.109)	(0.109)
Year=2018	-0.0082	-0.012	-0.025	0.039	0.029	0.015
	(0.105)	(0.106)	(0.104)	(0.107)	(0.106)	(0.105)
Constant	-8.82***	-8.85***	-9.53***	-10.8***	-9.62***	-10.7***
	(2.199)	(2.544)	(2.561)	(2.532)	(2.410)	(2.434)
Observations	745	745	745	765	765	765
R-squared	0.759	0.769	0.779	0.793	0.799	0.811

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, *p<0.1. Data on population dependent on agriculture are not available for Antigua and Barbuda, Dominica, Marshall Islands, Saint Kitts and Nevis, and Seychelles. Data on cropland are not available for Angola.

Table 2B. 4: Estimates of the effects of changes in the costs incurred in international trade on fertilizer imports, robustness check with information on country level Latitude and Longitude, full sample pooled OLS (dependent variable: log of fertilizer imports (MT))

	(1)	(2)	(3)	(4)
Time taken in documentary compliance (hours)	-0.0022	-0.0019	-0.0034*	-0.0045*
	(0.00167)	(0.00170)	(0.00168)	(0.00202)
Time taken in border compliance (hours)	-0.0029	-0.0031*	-0.0039*	-0.0059***
	(0.00154)	(0.00157)	(0.00166)	(0.00163)
Cost of documentary compliance (% of current GNI per capita)	0.0022	0.0020	0.0033	0.000071
	(0.00250)	(0.00244)	(0.00213)	(0.00274)
Cost of border compliance (% of current GNI per capita)	-0.0035*	-0.0030	-0.0028	-0.0011
	(0.00170)	(0.00168)	(0.00171)	(0.00186)
ln(GDP, constant 2010 USD)	1.51*	1.48*	1.59*	1.29
	(0.707)	(0.710)	(0.734)	(0.739)
ln(Population)	0.53	0.64	0.14	-1.07
	(1.316)	(1.293)	(1.265)	(1.354)
Ag GDP (% of total GDP)		-0.015	-0.014	-0.015
		(0.0339)	(0.0338)	(0.0347)
Rural population (% of total population)		0.13	0.14	0.15
		(0.0833)	(0.0795)	(0.0805)
ln(Annual rainfall, mm)		-0.15	-0.15	-0.15
		(0.150)	(0.150)	(0.149)
ln(Annual crop area harvested, ha)		-0.20	-0.21	-0.20
		(0.137)	(0.137)	(0.143)
Government Effectiveness, Percentile Rank (0-100)			0.0039	0.0043
			(0.00890)	(0.00892)
Control of Corruption, Percentile Rank (0-100)			0.014*	0.014*
			(0.00675)	(0.00675)
Country is landlocked=1			0.086	0.18
			(0.256)	(0.261)
Domestic production of fertilizer, mn tons				0.035
				(0.0345)
Latitude	0.0038	0.0025	0.0020	0.00053
	(0.00446)	(0.00456)	(0.00485)	(0.00567)
Longitude	-0.0010	-0.0011	-0.00076	-0.0033
	(0.00247)	(0.00264)	(0.00264)	(0.00222)
Time avg: ln(GDP, constant 2010 USD)	0.0053	0.0016	0.28	0.34**
	(0.222)	(0.226)	(0.201)	(0.114)
Time(Population)	0.84**	0.78**	0.50*	0.97***

Table 2B. 4 (cont'd)

	(0.271)	(0.272)	(0.235)	(0.119)
Time avg: Ag GDP (% of total GDP)		-0.046	-0.042	-0.037
		(0.0283)	(0.0285)	(0.0299)
Time avg: Rural population (% of total population)		-0.0085	-0.011	-0.0084
		(0.00858)	(0.00889)	(0.0102)
Time avg: ln(Annual rainfall, mm)		0.20	0.22	0.20
		(0.110)	(0.112)	(0.114)
Time avg: ln(Annual crop area harvested, ha)		0.45***	0.44***	0.44***
		(0.0883)	(0.0926)	(0.0979)
Time avg: Government Effectiveness, Percentile Rank (0-100)			0.014	0.013
			(0.0192)	(0.0202)
Time avg: Control of Corruption, Percentile Rank (0-100)			0.0050	0.0046
			(0.0127)	(0.0135)
Time avg: Domestic production of fertilizer, mn tons				-0.061**
				(0.0231)
Year=2015	-0.030	-0.025	-0.019	-0.046
	(0.0611)	(0.0611)	(0.0612)	(0.0616)
Year=2016	0.041	0.049	0.058	0.012
	(0.0710)	(0.0705)	(0.0698)	(0.0694)
Year=2017	0.061	0.072	0.077	0.0085
	(0.109)	(0.109)	(0.110)	(0.109)
Year=2018	0.021	0.034	0.041	-0.080
	(0.105)	(0.106)	(0.107)	(0.112)
Constant	-9.81***	-8.76***	-10.2***	-12.1***
	(2.416)	(2.419)	(2.746)	(1.716)
Observations	775	765	765	765
R-squared	0.811	0.799	0.792	0.760

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1. Latitude and longitude data for Sudan was missing reducing the analytical sample to 775 observations. Data on agricultural GDP are missing for Barbados and Libya for all years, thus reducing the analytical sample to 765 observations.

Table 2B. 5: Estimates of the effects of changes in the costs incurred in international trade on fertilizer imports, robustness check with regional dummies, full sample pooled OLS (dependent variable: log of fertilizer imports (MT))

	(1)	(2)	(3)	(4)
Time taken in documentary compliance (hours)	-0.0032*	-0.0031*	-0.0022	-0.0026
	(0.00158)	(0.00150)	(0.00157)	(0.00156)
Time taken in border compliance (hours)	-0.0025	-0.0015	-0.0011	-0.00060
	(0.00148)	(0.00151)	(0.00145)	(0.00147)
Cost of documentary compliance (% of current GNI per capita)	-0.0011	0.0020	0.0011	0.0013
	(0.00250)	(0.00200)	(0.00229)	(0.00229)
Cost of border compliance (% of current GNI per capita)	-0.0035	-0.0040*	-0.0039*	-0.0043**
	(0.00187)	(0.00164)	(0.00156)	(0.00158)
ln(GDP, constant 2010 USD)	1.06	1.41*	1.36	1.38*
	(0.682)	(0.706)	(0.689)	(0.685)
ln(Population)	-0.28	0.50	0.90	0.82
	(1.261)	(1.236)	(1.281)	(1.304)
Ag GDP (% of total GDP)		-0.018	-0.017	-0.017
		(0.0255)	(0.0249)	(0.0249)
Rural population (% of total population)		0.14	0.13	0.12
		(0.0786)	(0.0780)	(0.0819)
ln(Annual rainfall, mm)		-0.14	-0.14	-0.14
		(0.149)	(0.151)	(0.151)
ln(Annual crop area harvested, ha)		-0.21	-0.21	-0.21
		(0.138)	(0.136)	(0.135)
Government Effectiveness, Percentile Rank (0-100)			0.0047	0.0044
			(0.00881)	(0.00877)
Control of Corruption, Percentile Rank (0-100)			0.014*	0.014*
			(0.00653)	(0.00653)
Country is landlocked=1			0.27	0.17
			(0.263)	(0.259)
Domestic production of fertilizer, mn tons				0.035
				(0.0364)
North America	1.59**	0.71	0.48	1.22
	(0.502)	(0.532)	(0.579)	(0.639)
Eastern Asia	0.33	0.55	0.42	1.17
	(0.579)	(0.652)	(0.697)	(0.684)
South Asia	0.15	0.54	0.43	0.54
	(0.370)	(0.527)	(0.548)	(0.554)
South East Asia	0.81	1.03	1.01	1.06

Table 2B. 5 (cont'd)

	(0.414)	(0.601)	(0.663)	(0.671)
Southern Europe	1.44***	1.18*	1.23*	1.34*
	(0.422)	(0.522)	(0.560)	(0.563)
Australia and New Zealand	3.26***	2.50**	2.28*	2.37**
	(0.471)	(0.861)	(0.882)	(0.905)
Melanasia	0.88*	0.97	0.97	1.09
	(0.432)	(0.600)	(0.611)	(0.613)
Micronesia	-3.98***	-4.65***	-4.97***	-4.55***
	(0.467)	(0.740)	(0.887)	(0.865)
Polynesia	-1.47	-1.94	-1.85	-1.69
	(1.297)	(1.495)	(1.609)	(1.639)
Central Asia	-0.58	-0.49	-0.44	-0.35
	(0.986)	(0.898)	(0.926)	(0.924)
West Asia	0.48	0.82	0.87	0.96
	(0.359)	(0.442)	(0.483)	(0.490)
Eastern Europe	1.52**	0.87	0.92	1.14
	(0.546)	(0.653)	(0.647)	(0.584)
Northern Europe	3.02***	2.48***	2.34***	2.44***
	(0.451)	(0.562)	(0.632)	(0.636)
Western Europe	2.20***	1.95**	1.66*	1.83*
	(0.544)	(0.639)	(0.704)	(0.710)
Sub-Saharan Africa	-0.061	-0.042	-0.18	-0.12
	(0.372)	(0.500)	(0.527)	(0.526)
Latin America and the Caribbean	1.41***	1.08	1.09	1.23*
	(0.373)	(0.588)	(0.620)	(0.621)
Time avg: ln(GDP, constant 2010 USD)	-0.035	-0.0045	-0.082	-0.10
	(0.0968)	(0.145)	(0.149)	(0.151)
Time(Population)	1.25***	0.68**	0.80***	0.86***
	(0.101)	(0.204)	(0.205)	(0.211)
Time avg: Ag GDP (% of total GDP)		-0.033	-0.037	-0.039
		(0.0244)	(0.0246)	(0.0245)
Time avg: Rural population (% of total population)		-0.0058	-0.0062	-0.0041
		(0.00829)	(0.00850)	(0.00841)
Time avg: ln(Annual rainfall, mm)		0.062	0.11	0.069
		(0.144)	(0.147)	(0.147)
Time avg: ln(Annual crop area harvested, ha)		0.45***	0.44***	0.44***
		(0.0827)	(0.0816)	(0.0835)
Time avg: Government Effectiveness, Percentile Rank (0-100)			-0.0070	-0.0049

Table 2B. 5 (cont'd)

			(0.0124)	(0.0123)
Time avg: Control of Corruption, Percentile Rank (0-100)			0.015	0.014
			(0.00971)	(0.00916)
Time avg: Domestic production of fertilizer, mn tons				-0.050*
				(0.0209)
Year=2015	-0.045	-0.023	-0.030	-0.035
	(0.0583)	(0.0594)	(0.0600)	(0.0599)
Year=2016	0.014	0.051	0.041	0.032
	(0.0676)	(0.0689)	(0.0696)	(0.0701)
Year=2017	0.021	0.073	0.066	0.055
	(0.107)	(0.109)	(0.108)	(0.108)
Year=2018	-0.049	0.043	0.032	0.019
	(0.109)	(0.106)	(0.105)	(0.105)
Constant	-8.48***	-6.13**	-6.83***	-7.23***
	(1.478)	(1.906)	(1.820)	(1.828)
Observations	780	770	770	770
R-squared	0.835	0.855	0.859	0.865

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1. Data on agricultural GDP are missing for Barbados and Libya for all years, thus reducing the analytical sample to 765 observations; Base category for regional dummies is North Africa.

Table 2B. 6: Estimates of the effects of changes in the costs incurred in international trade on fertilizer imports, robustness check with net importing countries only, (dependent variable: log of net fertilizer imports (imports-exports) (MT))

	(1)	(2)	(3)	(4)
Time taken in documentary compliance (hours)	-0.0014	-0.0020	-0.0017	-0.0020
	(0.00172)	(0.00163)	(0.00163)	(0.00164)
Time taken in border compliance (hours)	-0.0037*	-0.0022	-0.0022	-0.0019
	(0.00180)	(0.00197)	(0.00207)	(0.00212)
Cost of documentary compliance (% of current GNI per capita)	-0.0012	0.0015	0.00079	0.00094
	(0.00308)	(0.00236)	(0.00261)	(0.00262)
Cost of border compliance (% of current GNI per capita)	-0.0032	-0.0047*	-0.0046*	-0.0049*
	(0.00234)	(0.00245)	(0.00248)	(0.00255)
ln(GDP, constant 2010 USD)	0.78	0.72	0.80	0.84
	(0.739)	(0.732)	(0.724)	(0.725)
ln(Population)	0.95	1.30	1.49	1.45
	(1.682)	(1.781)	(1.850)	(1.854)
Ag GDP (% of total GDP)		-0.010	-0.0083	-0.0083
		(0.0274)	(0.0271)	(0.0269)
Rural population (% of total population)		0.039	0.037	0.037
		(0.0972)	(0.0970)	(0.0974)
ln(Annual rainfall, mm)		-0.085	-0.068	-0.070
		(0.164)	(0.168)	(0.166)
ln(Annual crop area harvested, ha)		-0.17	-0.18	-0.18
		(0.122)	(0.118)	(0.119)
Government Effectiveness, Percentile Rank (0-100)			-0.0022	-0.0013
			(0.00818)	(0.00839)
Control of Corruption, Percentile Rank (0-100)			0.017*	0.017*
			(0.00789)	(0.00785)
Country is landlocked=1			0.22	0.18
			(0.253)	(0.257)
Domestic production of fertilizer, mn tons				-0.18
				(0.157)
Time avg: ln(GDP, constant 2010 USD)	0.40**	0.27	0.26	0.27
	(0.119)	(0.206)	(0.281)	(0.279)
Time(Population)	0.85***	0.42	0.47	0.49
	(0.125)	(0.282)	(0.320)	(0.324)
Time avg: Ag GDP (% of total GDP)		-0.013	-0.017	-0.018
		(0.0273)	(0.0271)	(0.0271)
Time avg: Rural population (% of total population)		-0.014	-0.015	-0.013

Table 2B. 6 (cont'd)

		(0.0101)	(0.00984)	(0.00988)
Time avg: ln(Annual rainfall, mm)		0.14	0.19	0.18
		(0.137)	(0.151)	(0.153)
Time avg: ln(Annual crop area harvested, ha)		0.47**	0.46**	0.46**
		(0.163)	(0.169)	(0.171)
Time avg: Government Effectiveness, Percentile Rank (0-100)			-0.0069	-0.0074
			(0.0163)	(0.0163)
Time avg: Control of Corruption, Percentile Rank (0-100)			0.0080	0.0095
			(0.0101)	(0.0102)
Time avg: Domestic production of fertilizer, mn tons				-0.054
				(0.0417)
Year=2015	-0.019	-0.016	-0.025	-0.024
	(0.0621)	(0.0640)	(0.0650)	(0.0648)
Year=2016	0.046	0.050	0.041	0.041
	(0.0750)	(0.0785)	(0.0783)	(0.0781)
Year=2017	0.065	0.080	0.069	0.071
	(0.105)	(0.108)	(0.107)	(0.107)
Year=2018	-0.071	-0.036	-0.057	-0.054
	(0.134)	(0.134)	(0.129)	(0.129)
Constant	-11.9***	-8.82**	-9.39**	-9.92**
	(1.729)	(2.728)	(3.347)	(3.370)
Observations	570	565	565	565
R-squared	0.801	0.825	0.827	0.829

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1. Data on agricultural GDP are missing for Barbados and Libya for all years, thus reducing the analytical sample to 565 observations; Base category for regional dummies is North Africa.

Table 2B. 7: Estimates of the effects of fertilizer-specific regulations on fertilizer imports, pooled OLS of EBA countries (dependent variable: log of fertilizer imports (MT))

		(1)	(2)	(3)	(4)	(5)
Must private entities obtain an import permit to import fertilizer products? (Base: No permit required)	Yes, a blank permit with no restriction on volume purchased or number of shipments	-0.27	-0.28	-0.16	-0.27	-0.48
		(0.417)	(0.416)	(0.426)	(0.500)	(0.500)
	Yes, a permit is required per shipment, or restrictions exist on volume imported	0.15	0.16	-0.055	-0.22	-0.39
		(0.294)	(0.290)	(0.288)	(0.311)	(0.311)
Must private entities register a new fertilizer in order to sell it in country? (Base= No registration needed)	Yes, but registration need not be renewed periodically	0.51	0.49	0.46	0.47	0.57
		(0.395)	(0.420)	(0.517)	(0.506)	(0.542)
	Yes, registration is time-limited and needs to be renewed periodically	0.28	0.18	0.23	0.27	0.33
		(0.336)	(0.330)	(0.379)	(0.374)	(0.370)
Time taken in documentary compliance (hours)			-0.0036	-0.00086	-0.00063	-0.0021
			(0.00357)	(0.00253)	(0.00265)	(0.00292)
Time taken in border compliance (hours)			0.00074	-0.00023	-0.0011	-0.00057
			(0.00289)	(0.00286)	(0.00306)	(0.00325)
Cost of documentary compliance (% of current GNI per capita)			0.0018	0.0017	0.0014	0.0024
			(0.00305)	(0.00265)	(0.00308)	(0.00325)
Cost of border compliance (% of current GNI per capita)			-0.0092	-0.0082	-0.0074	-0.0092
			(0.00659)	(0.00667)	(0.00748)	(0.00818)
ln(GDP, constant 2010 USD)		7.21	6.53	9.02	6.01	5.98
		(6.405)	(6.489)	(7.696)	(7.185)	(7.527)
ln(Population)		5.84	4.87	4.36	5.22	4.93
		(10.59)	(11.02)	(7.191)	(7.014)	(7.099)
Ag GDP (% of total GDP)				0.012	0.023	0.024
				(0.0631)	(0.0664)	(0.0646)
Rural population (% of total population)				0.54	0.50	0.49
				(0.642)	(0.691)	(0.736)
ln(Annual rainfall, mm)				-0.49	-0.51	-0.55

Table 2B. 7 (cont'd)

			(0.332)	(0.352)	(0.371)
ln(Annual crop area harvested, ha)			-2.70	-2.84	-2.87
			(2.532)	(2.489)	(2.508)
Government Effectiveness, Percentile Rank (0-100)				0.048	0.050
				(0.0517)	(0.0522)
Control of Corruption, Percentile Rank (0-100)				0.022	0.021
				(0.0338)	(0.0345)
Country is landlocked=1				0.15	0.046
				(0.452)	(0.458)
Domestic production of fertilizer, mn tons					-0.089
					(0.936)
Time avg: ln(GDP, constant 2010 USD)	0.67***	0.46***	0.22	0.24	0.052
	(0.0849)	(0.112)	(0.227)	(0.330)	(0.347)
Time(Population)	0.11	0.36*	0.43	0.53	0.77*
	(0.160)	(0.172)	(0.285)	(0.327)	(0.359)
Time avg: Ag GDP (% of total GDP)			-0.031	-0.038	-0.045
			(0.0306)	(0.0324)	(0.0323)
Time avg: Rural population (% of total population)			-0.0067	-0.0079	-0.010
			(0.0121)	(0.0123)	(0.0115)
Time avg: ln(Annual rainfall, mm)			0.37*	0.44*	0.31
			(0.168)	(0.172)	(0.195)
Time avg: ln(Annual crop area harvested, ha)			0.18	0.17	0.25
			(0.195)	(0.176)	(0.193)
Time avg: Government Effectiveness, Percentile Rank (0-100)				-0.019	-0.015
				(0.0186)	(0.0182)
Time avg: Control of Corruption, Percentile Rank (0-100)				0.017	0.016
				(0.0115)	(0.0107)
Time avg: Domestic production of fertilizer, mn tons					-0.077

Table 2B. 7 (cont'd)

					(0.0509)
Year=2018	-0.41	-0.39	-0.35	-0.26	-0.26
	(0.286)	(0.297)	(0.320)	(0.256)	(0.264)
Constant	-6.47**	-5.03*	-5.04	-6.91	-6.51
	(2.415)	(2.444)	(2.982)	(4.414)	(4.569)
Observations	118	118	118	118	118
R-squared	0.573	0.598	0.644	0.657	0.672

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1. Even though the EBA data contain comparable data for 62 countries, 3 countries are dropped from the sample due to a lack of data on fertilizer imports: Laos, Liberia, and Haiti

Table 2B. 8: Estimates of the effects of changes in the time and costs incurred in international trade on fertilizer imports, pooled OLS on the sample of EBA countries – model specifications comparable to Table 2.2 (dependent variable: log of fertilizer imports (MT))

	(1)	(2)	(3)	(4)
Time taken in documentary compliance (hours)	-0.0025	-0.0011	-0.00090	-0.0016
	(0.00256)	(0.00172)	(0.00183)	(0.00212)
Time taken in border compliance (hours)	0.00058	-0.00037	-0.00095	-0.0022
	(0.00243)	(0.00222)	(0.00222)	(0.00253)
Cost of documentary compliance (% of current GNI per capita)	0.0019	0.0015	0.00073	0.00065
	(0.00259)	(0.00237)	(0.00285)	(0.00300)
Cost of border compliance (% of current GNI per capita)	-0.0084	-0.0070	-0.0048	-0.0021
	(0.00696)	(0.00571)	(0.00657)	(0.00739)
ln(GDP, constant 2010 USD)	0.44	0.61	0.65	0.94
	(1.488)	(1.428)	(1.507)	(1.580)
ln(Population)	-2.13	-1.99	-2.31	-2.16
	(2.144)	(1.597)	(1.723)	(1.804)
Ag GDP (% of total GDP)		-0.040*	-0.039	-0.039
		(0.0194)	(0.0197)	(0.0221)
Rural population (% of total population)		0.20	0.20	0.24
		(0.135)	(0.137)	(0.142)
ln(Annual rainfall, mm)		-0.46*	-0.44*	-0.39
		(0.212)	(0.217)	(0.202)
ln(Annual crop area harvested, ha)		-0.83*	-0.92*	-0.92*
		(0.407)	(0.410)	(0.427)
Government Effectiveness, Percentile Rank (0-100)			0.0077	0.0046
			(0.0169)	(0.0175)
Control of Corruption, Percentile Rank (0-100)			0.018*	0.019*
			(0.00803)	(0.00871)
Country is landlocked=1			0.23	0.30
			(0.417)	(0.444)
Domestic production of fertilizer, mn tons				0.19
				(0.107)
Time avg: ln(GDP, constant 2010 USD)	0.50***	0.36	0.34	0.36
	(0.111)	(0.186)	(0.273)	(0.284)
Time avg: ln(Population)	0.35*	0.41	0.51*	0.60*
	(0.171)	(0.231)	(0.240)	(0.287)
Time avg: Ag GDP (% of total GDP)		-0.015	-0.023	-0.026
		(0.0297)	(0.0279)	(0.0267)
Time avg: Rural population (% of total population)		-0.0061	-0.0069	-0.0079

Table 2B. 8 (cont'd)

		(0.00978)	(0.0100)	(0.0100)
Time avg: ln(Annual rainfall, mm)		0.48***	0.52***	0.52***
		(0.124)	(0.119)	(0.118)
Time avg: ln(Annual crop area harvested, ha)		0.091	0.099	0.098
		(0.176)	-0.011	-0.0090
Time avg: Government Effectiveness, Percentile Rank (0-100)			-0.011	-0.0090
			(0.0162)	(0.0159)
Time avg: Control of Corruption, Percentile Rank (0-100)			0.015	0.012
			(0.0112)	(0.0106)
Time avg: Domestic production of fertilizer, mn tons				-0.12*
				(0.0578)
Year=2015	-0.052	0.013	0.016	0.0071
	(0.0976)	(0.0983)	(0.0940)	(0.0978)
Year=2016	0.060	0.16	0.17	0.16
	(0.103)	(0.0981)	(0.0931)	(0.0974)
Year=2017	0.14	0.28	0.31	0.27
	(0.191)	(0.184)	(0.162)	(0.161)
Year=2018	0.12	0.28	0.30	0.26
	(0.204)	(0.165)	(0.153)	(0.156)
Constant	-6.03*	-7.81**	-9.57*	-6.85
	(2.484)	(2.420)	(3.697)	(3.619)
Observations	295	295	295	295
R-squared	0.595	0.656	0.668	0.683

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1.

Table 2B. 9: Estimates of the effects of changes in the time and costs incurred in international trade on fertilizer imports, pooled OLS of EBA countries for 2017 and 2018 only (dependent variable: log of fertilizer imports (MT))

	(1)	(2)	(3)	(4)
Time taken in documentary compliance (hours)	-0.0035	-0.0020	-0.0012	-0.0022
	(0.00381)	(0.00283)	(0.00296)	(0.00295)
Time taken in border compliance (hours)	0.0014	0.00085	0.00078	0.0016
	(0.00264)	(0.00230)	(0.00212)	(0.00205)
Cost of documentary compliance (% of current GNI per capita)	0.0046	0.0036	0.0018	0.0030
	(0.00327)	(0.00261)	(0.00306)	(0.00309)
Cost of border compliance (% of current GNI per capita)	-0.0053	-0.0047	-0.0024	-0.0048
	(0.00667)	(0.00688)	(0.00655)	(0.00679)
ln(GDP, constant 2010 USD)	8.99	10.5	9.86	8.76
	(6.311)	(7.139)	(7.020)	(7.003)
ln(Population)	-21.5*	-19.8	-24.6*	-25.3*
	(9.860)	(10.58)	(10.95)	(10.20)
Ag GDP (% of total GDP)		-0.16*	-0.17*	-0.17*
		(0.0591)	(0.0721)	(0.0756)
Rural population (% of total population)		-0.096	-0.11	-0.15
		(0.429)	(0.435)	(0.428)
ln(Annual rainfall, mm)		-1.20***	-1.23**	-1.44**
		(0.332)	(0.375)	(0.487)
ln(Annual crop area harvested, ha)		-1.48	-1.97	-2.03
		(1.689)	(1.674)	(1.696)
Government Effectiveness, Percentile Rank (0-100)			-0.033	-0.016
			(0.0430)	(0.0463)
Control of Corruption, Percentile Rank (0-100)			0.0052	-0.00073
			(0.0262)	(0.0256)
Country is landlocked=1			0.44	0.33
			(0.418)	(0.417)
Domestic production of fertilizer, mn tons				-0.76
				(0.757)
Time avg: ln(GDP, constant 2010 USD)	0.33	0.47	0.64*	0.72*
	(0.222)	(0.247)	(0.269)	(0.290)
Time avg: ln(Population)	-0.086	-0.32	-0.24	-0.18
	(0.330)	(0.312)	(0.307)	(0.273)
Time avg: Ag GDP (% of total GDP)		-0.025	-0.029	-0.031
		(0.0303)	(0.0295)	(0.0291)
Time avg: Rural population (% of total population)		-0.015	-0.019	-0.018

Table 2B. 9 (cont'd)

		(0.0108)	(0.0119)	(0.0115)
Time avg: ln(Annual rainfall, mm)		0.24	0.28	0.14
		(0.151)	(0.145)	(0.165)
Time avg: ln(Annual crop area harvested, ha)		0.085	0.059	0.11
		(0.152)	(0.152)	(0.152)
Time avg: Government Effectiveness, Percentile Rank (0-100)			-0.0017	0.00038
			(0.0171)	(0.0165)
Time avg: Control of Corruption, Percentile Rank (0-100)			0.0069	0.0058
			(0.0102)	(0.00951)
Time avg: Domestic production of fertilizer, mn tons				-0.019
				(0.0555)
Year=2018	0.48**	0.23	0.16	0.11
	(0.144)	(0.223)	(0.332)	(0.331)
Constant	-5.27*	-3.54	-4.58	-4.29
	(2.427)	(3.213)	(4.435)	(4.623)
Observations	118	118	118	118
R-squared	0.614	0.677	0.688	0.704

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1.

Table 2B. 10: Estimates of the effects of changes in the time and costs incurred in international trade on fertilizer imports, pooled OLS of all countries for 2017 and 2018 only (dependent variable: log of fertilizer imports (MT))

	(1)	(2)	(3)	(4)
Time taken in documentary compliance (hours)	-0.0039	-0.0037	-0.0026	-0.0026
	(0.00249)	(0.00253)	(0.00267)	(0.00262)
Time taken in border compliance (hours)	-0.0051*	-0.0045*	-0.0046*	-0.0048**
	(0.00200)	(0.00195)	(0.00185)	(0.00175)
Cost of documentary compliance (% of current GNI per capita)	0.0024	0.0022	0.00091	0.0014
	(0.00289)	(0.00323)	(0.00372)	(0.00375)
Cost of border compliance (% of current GNI per capita)	-0.0016	-0.0017	-0.0014	-0.0015
	(0.00148)	(0.00141)	(0.00148)	(0.00147)
ln(GDP, constant 2010 USD)	2.95	6.34*	5.81*	5.51
	(2.816)	(2.908)	(2.927)	(2.920)
ln(Population)	-16.5**	-16.4*	-16.0*	-16.2*
	(6.113)	(6.763)	(7.003)	(6.966)
Ag GDP (% of total GDP)		-0.21*	-0.23**	-0.23**
		(0.0808)	(0.0874)	(0.0874)
Rural population (% of total population)		0.11	0.084	0.034
		(0.278)	(0.271)	(0.281)
ln(Annual rainfall, mm)		-1.20***	-1.44**	-1.23**
		(0.332)	(0.487)	(0.375)
ln(Annual crop area harvested, ha)		-1.48	-1.97	-2.03
		(1.689)	(1.674)	(1.696)
Government Effectiveness, Percentile Rank (0-100)			-0.031	-0.025
			(0.0297)	(0.0299)
Control of Corruption, Percentile Rank (0-100)			0.037	0.034
			(0.0297)	(0.0293)
Country is landlocked=1			0.17	0.11
			(0.283)	(0.283)
Domestic production of fertilizer, mn tons				-0.24
				(0.170)
Time avg: ln(GDP, constant 2010 USD)	0.34**	0.070	-0.075	-0.056
	(0.116)	(0.219)	(0.282)	(0.279)
Time avg: ln(Population)	0.95***	1.28***	1.45***	1.43***
	(0.131)	(0.228)	(0.293)	(0.291)
Time avg: Ag GDP (% of total GDP)		-0.039	-0.051	-0.054
		(0.0321)	(0.0322)	(0.0322)

Table 2B. 10 (cont'd)

Time avg: Rural population (% of total population)		-0.0095	-0.0090	-0.0085
		(0.00980)	(0.00969)	(0.00956)
Time avg: ln(Annual rainfall, mm)		0.24	0.28	0.14
		(0.151)	(0.145)	(0.165)
Time avg: ln(Annual crop area harvested, ha)		0.085	0.059	0.11
		(0.152)	(0.152)	(0.152)
Time avg: Government Effectiveness, Percentile Rank (0-100)			-0.0028	-0.0026
			(0.0192)	(0.0190)
Time avg: Control of Corruption, Percentile Rank (0-100)			0.011	0.011
			(0.0125)	(0.0122)
Time avg: Domestic production of fertilizer, mn tons				-0.087**
				(0.0282)
Year=2018	0.063	-0.081	-0.091	-0.093
	(0.128)	(0.141)	(0.140)	(0.138)
Constant	-11.7***	-9.70***	-9.25**	-9.18**
	(1.811)	(2.853)	(2.834)	(2.803)
Observations	312	308	308	308
R-squared	0.765	0.785	0.789	0.797

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1. Data on agricultural GDP are missing for Barbados and Libya for all years, thus reducing the analytical sample to 308 observations (154 countries).

Table 2B. 11: Estimates of the effects of changes in fertilizer-specific regulations on fertilizer imports, pooled OLS of EBA countries – without time averages (dependent variable: log of fertilizer imports (MT))

		(1)	(2)	(3)	(4)
Must private entities obtain an import permit to import fertilizer products? (Base: No permit required)	Yes, a blank permit with no restriction on volume purchased or number of shipments	-0.58 (0.593)	-0.58 (0.609)	-0.69 (0.597)	-0.69 (0.600)
	Yes, a permit is required per shipment, or restrictions exist on volume imported	-0.11 (0.415)	-0.11 (0.425)	-0.015 (0.379)	-0.015 (0.382)
Must private entities register a new fertilizer in order to sell it in country? (Base= No registration needed)	Yes, but registration need not be renewed periodically	1.12* (0.527)	1.11* (0.538)	0.98 (0.556)	0.98 (0.559)
	Yes, registration is time-limited and needs to be renewed periodically	0.23 (0.450)	0.23 (0.460)	0.26 (0.397)	0.26 (0.399)
Time taken in documentary compliance (hours)		-0.0041	-0.0041	-0.0030	-0.0030
		(0.00405)	(0.00417)	(0.00384)	(0.00386)
Time taken in border compliance (hours)		0.0062	0.0062	0.0048	0.0048
		(0.00312)	(0.00323)	(0.00305)	(0.00307)
Cost of documentary compliance (% of current GNI per capita)		0.00029	0.00032	0.0029	0.0029
		(0.00354)	(0.00362)	(0.00361)	(0.00363)
Cost of border compliance (% of current GNI per capita)		-0.025**	-0.025**	-0.023**	-0.023**
		(0.00786)	(0.00800)	(0.00769)	(0.00774)
ln(GDP, constant 2010 USD)		5.30	6.35	2.81	2.82
		(6.445)	(7.577)	(6.576)	(6.679)
ln(Population)		-0.20	0.75	2.92	2.96
		(12.10)	(8.205)	(7.535)	(7.458)
Ag GDP (% of total GDP)			-0.037	-0.017	-0.017
			(0.0694)	(0.0730)	(0.0734)
Rural population (% of total population)			0.39	0.37	0.38
			(0.713)	(0.736)	(0.748)
ln(Annual rainfall, mm)			0.45***	0.50***	0.51***
			(0.121)	(0.110)	(0.119)
ln(Annual crop area harvested, ha)			-0.81*	-0.90*	-0.92*
			(0.407)	(0.410)	(0.410)
Government Effectiveness, Percentile Rank (0-100)				0.054	0.054
				(0.0519)	(0.0524)
Control of Corruption, Percentile Rank (0-100)				0.028	0.028
				(0.0354)	(0.0356)

Table 2B. 11 (cont'd)

Country is landlocked=1			-1.21**	-1.21**
			(0.363)	(0.364)
Domestic production of fertilizer, mn tons				-0.040
				(0.103)
Year=2018	-0.24	-0.18	-0.092	-0.090
	(0.314)	(0.351)	(0.281)	(0.276)
Constant	12.6***	12.6***	12.8***	12.8***
	(0.488)	(0.482)	(0.460)	(0.463)
Observations	118	118	118	118
R-squared	0.295	0.296	0.392	0.392

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1. Even though the EBA data contain comparable data for 62 countries, 3 countries are dropped from the sample due to a lack of data on fertilizer imports: Laos, Liberia, and Haiti.

Table 2B. 12: Estimates of the effects of changes in the time and costs incurred in international trade on fertilizer imports, pooled OLS – high and upper middle income countries only (dependent variable: log of fertilizer imports (MT))

	(1)	(2)	(3)	(4)
Time taken in documentary compliance (hours)	-0.0021	-0.0016	0.0013	-0.00040
	(0.00341)	(0.00298)	(0.00285)	(0.00281)
Time taken in border compliance (hours)	-0.014***	-0.014***	-0.013***	-0.012***
	(0.00349)	(0.00318)	(0.00305)	(0.00307)
Cost of documentary compliance (% of current GNI per capita)	-0.15	-0.19	-0.19	-0.17
	(0.0901)	(0.0959)	(0.127)	(0.128)
Cost of border compliance (% of current GNI per capita)	-0.00096	0.016	0.046	0.040
	(0.0338)	(0.0418)	(0.0502)	(0.0501)
ln(GDP, constant 2010 USD)	-0.021	0.67	0.78	1.04
	(0.992)	(1.055)	(1.049)	(1.014)
ln(Population)	0.18	0.13	0.54	0.38
	(1.466)	(1.499)	(1.521)	(1.509)
Ag GDP (% of total GDP)		0.083	0.074	0.071
		(0.0464)	(0.0444)	(0.0451)
Rural population (% of total population)		0.079	0.078	0.054
		(0.0997)	(0.0985)	(0.107)
ln(Annual rainfall, mm)		-0.15	-0.16	-0.17
		(0.169)	(0.168)	(0.166)
ln(Annual crop area harvested, ha)		-0.19	-0.22	-0.22
		(0.118)	(0.126)	(0.125)
Government Effectiveness, Percentile Rank (0-100)			0.0021	0.0015
			(0.0104)	(0.00998)
Control of Corruption, Percentile Rank (0-100)			0.0072	0.0067
			(0.00697)	(0.00659)
Country is landlocked=1			0.25	0.19
			(0.364)	(0.364)
Domestic production of fertilizer, mn tons				0.000054
				(0.0000409)
Time avg: ln(GDP, constant 2010 USD)	0.050	0.14	-0.22	-0.23
	(0.200)	(0.327)	(0.272)	(0.264)
Time avg: ln(Population)	1.24***	1.25***	1.62***	1.60***
	(0.206)	(0.302)	(0.280)	(0.271)
Time avg: Ag GDP (% of total GDP)		0.059	0.079	0.085
		(0.0527)	(0.0448)	(0.0455)

Table 2B. 12 (cont'd)

Time avg: Rural population (% of total population)		-0.0059	-0.0044	-0.0039
		(0.0120)	(0.00936)	(0.00923)
Time avg: ln(Annual rainfall, mm)		0.15	0.12	0.047
		(0.161)	(0.144)	(0.139)
Time avg: ln(Annual crop area harvested, ha)		0.45***	0.49***	0.48***
		(0.0945)	(0.0869)	(0.0820)
Time avg: Government Effectiveness, Percentile Rank (0-100)			0.025	0.027
			(0.0239)	(0.0235)
Time avg: Control of Corruption, Percentile Rank (0-100)			0.0060	0.0062
			(0.0169)	(0.0164)
Time avg: Domestic production of fertilizer, mn tons				-0.088**
				(0.0283)
Year=2015	-0.022	-0.031	-0.035	-0.047
	(0.0524)	(0.0579)	(0.0574)	(0.0590)
Year=2016	0.056	0.067	0.057	0.030
	(0.0879)	(0.0936)	(0.0923)	(0.0921)
Year=2017	0.072	0.081	0.073	0.033
	(0.133)	(0.130)	(0.130)	(0.126)
Year=2018	-0.022	0.028	0.027	-0.023
	(0.136)	(0.138)	(0.138)	(0.137)
Constant	-8.64***	-11.0*	-10.2**	-9.72**
	(2.484)	(4.414)	(3.097)	(3.027)
Observations	495	485	485	485
R-squared	0.827	0.839	0.855	0.862

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1. Data on agricultural GDP are missing for Barbados and Libya for all years, thus reducing the analytical sample to 485 observations (97 countries).

Table 2B. 13: Estimates of the effects of changes in the time and costs incurred in international trade on fertilizer imports, pooled OLS – low and lower middle income countries only (dependent variable: log of fertilizer imports (MT))

	(1)	(2)	(3)	(4)
Time taken in documentary compliance (hours)	-0.0031	-0.0026	-0.0026	-0.0027
	(0.00233)	(0.00208)	(0.00247)	(0.00252)
Time taken in border compliance (hours)	-0.0031	-0.0034	-0.0043	-0.0044
	(0.00191)	(0.00207)	(0.00251)	(0.00245)
Cost of documentary compliance (% of current GNI per capita)	0.00089	0.00034	0.00079	0.0010
	(0.00289)	(0.00280)	(0.00324)	(0.00335)
Cost of border compliance (% of current GNI per capita)	-0.0025	-0.0037	-0.0033	-0.0034
	(0.00167)	(0.00198)	(0.00207)	(0.00213)
ln(GDP, constant 2010 USD)	1.78	1.58	1.44	1.44
	(1.124)	(0.972)	(0.967)	(0.974)
ln(Population)	-4.87	-2.27	-2.40	-2.28
	(3.587)	(3.204)	(3.297)	(3.353)
Ag GDP (% of total GDP)		-0.032	-0.038	-0.039
		(0.0301)	(0.0302)	(0.0305)
Rural population (% of total population)		0.25*	0.24*	0.25*
		(0.125)	(0.117)	(0.120)
ln(Annual rainfall, mm)		-0.037	-0.059	-0.049
		(0.340)	(0.348)	(0.337)
ln(Annual crop area harvested, ha)		-0.11	-0.13	-0.13
		(0.518)	(0.452)	(0.454)
Government Effectiveness, Percentile Rank (0-100)			0.0076	0.0072
			(0.0181)	(0.0182)
Control of Corruption, Percentile Rank (0-100)			0.031**	0.032**
			(0.0113)	(0.0114)
Country is landlocked=1			0.18	0.14
			(0.537)	(0.550)
Domestic production of fertilizer, mn tons				0.069
				(0.164)
Time avg: ln(GDP, constant 2010 USD)	0.44	-0.22	0.19	0.17
	(0.328)	(0.579)	(0.625)	(0.638)
Time avg: ln(Population)	0.85*	1.59*	1.30	1.32
	(0.415)	(0.727)	(0.681)	(0.694)
Time avg: Ag GDP (% of total GDP)		-0.074	-0.074	-0.078
		(0.0427)	(0.0420)	(0.0435)
Time avg: Rural population (% of total population)		0.0019	0.0047	0.0050

Table 2B. 13 (cont'd)

		(0.0174)	(0.0171)	(0.0168)
Time avg: ln(Annual rainfall, mm)		0.17	0.29	0.28
		(0.172)	(0.209)	(0.215)
Time avg: ln(Annual crop area harvested, ha)		0.50	0.36	0.36
		(0.348)	(0.346)	(0.345)
Time avg: Government Effectiveness, Percentile Rank (0-100)			-0.047	-0.045
			(0.0322)	(0.0333)
Time avg: Control of Corruption, Percentile Rank (0-100)			0.031	0.031
			(0.0217)	(0.0217)
Time avg: Domestic production of fertilizer, mn tons				-0.095
				(0.256)
Year=2015	-0.0034	0.031	0.020	0.018
	(0.168)	(0.172)	(0.179)	(0.180)
Year=2016	0.14	0.25	0.26	0.26
	(0.215)	(0.226)	(0.217)	(0.221)
Year=2017	0.24	0.40	0.41	0.40
	(0.312)	(0.354)	(0.341)	(0.346)
Year=2018	0.27	0.49	0.48	0.47
	(0.366)	(0.375)	(0.356)	(0.361)
Constant	-13.2***	-8.71	-13.5*	-13.2*
	(3.491)	(4.879)	(5.860)	(5.953)
Observations	285	285	285	285
R-squared	0.619	0.651	0.675	0.676

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1

Table 2B. 14: Estimates of effect of changes in fertilizer specific regulations on fertilizer imports, pooled OLS of high and upper middle income EBA countries (dependent variable: log of fertilizer imports (MT))

		(1)	(2)	(3)	(4)
Must private entities obtain an import permit to import fertilizer products? (Base: No permit required)	Yes, a blank permit with no restriction on volume purchased or number of shipments	1.17* (0.500)	1.01** (0.319)	0.85 (0.540)	0.61 (0.698)
	Yes, a permit is required per shipment, or restrictions exist on volume imported	0.50 (0.446)	0.21 (0.350)	0.025 (0.238)	-0.035 (0.250)
Must private entities register a new fertilizer in order to sell it in country? (Base= No registration needed)	Yes, but registration need not be renewed periodically	-0.66 (0.523)	-0.42 (0.268)	-0.040 (0.476)	0.027 (0.486)
	Yes, registration is time-limited and needs to be renewed periodically	-0.64 (0.532)	0.10 (0.391)	0.30 (0.568)	0.32 (0.562)
Time taken in documentary compliance (hours)		-0.0075 (0.0103)	0.0091 (0.0112)	-0.0041 (0.0156)	-0.0036 (0.0151)
Time taken in border compliance (hours)		0.0015 (0.00773)	-0.014* (0.00626)	-0.016* (0.00857)	-0.016* (0.00917)
Cost of documentary compliance (% of current GNI per capita)		-0.60*** (0.150)	-0.44 (0.296)	-0.86** (0.251)	-0.87*** (0.222)
Cost of border compliance (% of current GNI per capita)		0.081* (0.0385)	0.011 (0.0638)	0.088 (0.0786)	0.078 (0.0843)
ln(GDP, constant 2010 USD)		4.11 (5.901)	0.24 (7.136)	-5.02 (8.850)	-9.27 (8.274)
ln(Population)		17.5 (10.95)	20.7 (15.19)	17.1 (18.04)	7.91 (16.10)
Ag GDP (% of total GDP)			0.077 (0.265)	0.040 (0.289)	-0.047 (0.289)
Rural population (% of total population)			0.69 (0.571)	0.66 (0.501)	0.70 (0.470)
ln(Annual rainfall, mm)			-0.19 (0.411)	-0.018 (0.380)	-0.13 (0.372)
ln(Annual crop area harvested, ha)			-0.19 (3.053)	-0.68 (2.789)	-1.49 (2.119)

Table 2B. 14 (cont'd)

Government Effectiveness, Percentile Rank (0-100)			-0.015	-0.0061
			(0.0394)	(0.0305)
Control of Corruption, Percentile Rank (0-100)			0.0060	0.0036
			(0.0210)	(0.0187)
Country is landlocked=1			0.092	-0.072
			(0.744)	(0.888)
Domestic production of fertilizer, mn tons				-1.6
				(0.817)
Time avg: ln(GDP, constant 2010 USD)	0.50	0.43	-0.54	-0.70
	(0.249)	(0.750)	(0.764)	(0.664)
Time avg: ln(Population)	0.034	0.58	1.63	1.75*
	(0.324)	(0.708)	(0.861)	(0.810)
Time avg: Ag GDP (% of total GDP)		0.068	0.11	0.11
		(0.0519)	(0.0665)	(0.0776)
Time avg: Rural population (% of total population)		-0.0021	-0.030	-0.035
		(0.0323)	(0.0250)	(0.0190)
Time avg: ln(Annual rainfall, mm)		0.92**	0.53	0.52
		(0.265)	(0.340)	(0.391)
Time avg: ln(Annual crop area harvested, ha)		-0.085	0.21	0.21
		(0.169)	(0.171)	(0.205)
Time avg: Government Effective-ness, Percentile Rank (0-100)			-0.011	-0.0098
			(0.0282)	(0.0273)
Time avg: Control of Corruption, Percentile Rank (0-100)			0.031	0.031
			(0.0197)	(0.0178)
Time avg: Domestic production of fertilizer, mn tons				-0.045
				(0.0937)
Year=2018	-0.30	-0.18	-0.014	0.19
	(0.209)	(0.301)	(0.308)	(0.317)
Constant	0.040	-8.18	-0.57	1.64
	(3.323)	(9.926)	(6.463)	(4.692)
Observations	48	48	48	48
R-squared	0.844	0.925	0.946	0.951

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1

Table 2B. 15: Estimates of effect of changes in fertilizer specific regulations on fertilizer imports, pooled OLS of low and lower middle income EBA countries only (dependent variable: log of fertilizer imports (MT))

		(1)	(2)	(3)	(4)
Must private entities obtain an import permit to import fertilizer products? (Base: No permit required)	Yes, a blank permit with no restriction on volume purchased or number of shipments	-1.15* (0.551)	-1.37** (0.476)	-2.10* (0.797)	-3.07** (0.929)
	Yes, a permit is required per shipment, or restrictions exist on volume imported	-0.44 (0.358)	-0.56 (0.411)	-1.00 (0.676)	-1.19 (0.709)
Must private entities register a new fertilizer in order to sell it in country? (Base= No registration needed)	Yes, but registration need not be renewed periodically	0.86 (0.695)	1.10 (0.801)	1.42 (0.859)	1.65* (0.711)
	Yes, registration is time-limited and needs to be renewed periodically	0.58 (0.372)	0.40 (0.436)	0.52 (0.399)	0.65 (0.416)
Time taken in documentary compliance (hours)		-0.0040 (0.00307)	-0.0054 (0.00406)	-0.0047 (0.00439)	-0.0021 (0.00472)
Time taken in border compliance (hours)		-0.00090 (0.00279)	-0.0014 (0.00306)	-0.0031 (0.00373)	-0.0068 (0.00472)
Cost of documentary compliance (% of current GNI per capita)		0.0016 (0.00392)	-0.0012 (0.00376)	-0.0012 (0.00383)	-0.0052 (0.00378)
Cost of border compliance (% of current GNI per capita)		-0.0056 (0.00661)	-0.0044 (0.00836)	-0.0044 (0.0109)	0.0081 (0.0131)
ln(GDP, constant 2010 USD)		10.6 (8.997)	14.2 (12.02)	4.48 (14.38)	5.62 (15.55)
ln(Population)		12.3 (15.68)	11.7 (12.09)	22.1 (18.47)	20.1 (17.94)
Ag GDP (% of total GDP)			0.042 (0.0807)	0.062 (0.115)	0.10 (0.116)
Rural population (% of total population)			0.79 (1.059)	1.08 (1.000)	0.91 (1.139)
ln(Annual rainfall, mm)			-0.49 (0.332)	-0.51 (0.352)	-0.52 (0.371)
ln(Annual crop area harvested, ha)			0.17 (0.159)	0.20 (0.200)	0.25 (0.201)
Government Effectiveness, Percentile Rank (0-100)				0.10 (0.0939)	0.11 (0.0951)
Control of Corruption, Percentile Rank (0-100)				0.061 (0.120)	0.063 (0.125)

Table 2B. 15 (cont'd)

Country is landlocked=1			-0.37	0.077
			(0.904)	(0.861)
Domestic production of fertilizer, mn tons				0.95
				(0.814)
Time avg: ln(GDP, constant 2010 USD)	0.54	-0.47	-0.46	0.070
	(0.370)	(0.498)	(1.025)	(0.971)
Time avg: ln(Population)	0.26	1.67**	1.68	1.23
	(0.401)	(0.607)	(0.948)	(0.904)
Time avg: Ag GDP (% of total GDP)		-0.055	-0.063	-0.029
		(0.0359)	(0.0439)	(0.0446)
Time avg: Rural population (% of total population)		-0.019	-0.017	-0.025
		(0.0158)	(0.0166)	(0.0148)
Time avg: ln(Annual rainfall, mm)		0.37*	0.44*	0.31
		(0.168)	(0.172)	(0.195)
Time avg: ln(Annual crop area harvested, ha))		0.18	0.17	0.25
		(0.195)	(0.176)	(0.193)
Time avg: Government Effectiveness, Percentile Rank (0-100)			-0.033	-0.061*
			(0.0262)	(0.0273)
Time avg: Control of Corruption, Percentile Rank (0-100)			0.033	0.051*
			(0.0219)	(0.0248)
Time avg: Domestic production of fertilizer, mn tons				0.48*
				(0.206)
Year=2018	-0.77	-0.65	-0.36	-0.44
	(0.484)	(0.566)	(0.655)	(0.685)
Constant	-4.80	-1.64	-1.38	-6.98
	(3.788)	(5.336)	(11.61)	(10.85)
Observations	70	70	70	70
R-squared	0.544	0.605	0.648	0.712

Notes: Numbers in parentheses are standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1

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CHAPTER 3

DOES PRICE UNCERTAINTY AFFECT THE PRICE LEVELS OF STAPLE FOOD PRODUCTS IN A DEVELOPING COUNTRY CONTEXT? EVIDENCE FROM THE ZAMBIAN MAIZE MARKETS

3.1 Introduction

High price volatility of food products can have adverse effects on consumers and producers of agricultural products. Sudden food price spikes have been found to endanger the food and nutritional security of vulnerable populations in developing countries (Robles, Torero, and Cuesta, 2010; de Brauw A, 2011; Arndt, Hussain, and Østerdal, 2012), even leading to socio-political turmoil (Bellemare, 2014). Risk associated with highly volatile prices of staple food products tends to push small farmers in developing countries towards food self-sufficiency and thus discourages agricultural diversification (Fafchamps, 1992; Poulton, et al., 2006). On the other hand, commercial farmers can be discouraged from investing in the production of agricultural products with highly volatile prices if they are risk averse (Sandmo, 1971; Seale and Shonkwiler, 1987; Finkelshtain and Chalfant, 1991; Rezitis and Stavropoulos, 2009). Such commercial farmers are often crucial to the food security of developing countries (Myers, 2006; Poulton et al., 2006).

Despite the well accepted adverse effects of price volatility, if and how best to manage volatile food prices in developing countries is a highly contentious issue among researchers. Some have emphasized the inevitable role of the state in ensuring stable food prices (Poulton et al., 2006), albeit with the caveat that government intervention should occur under the pre-conditions of market failure or an exceptional food crisis (Cummings Jr. et al., 2006). Others have considered safeguarding vulnerable populations through safety nets (Alderman and Haque, 2006) and establishing international food buffer stocks to address shortfalls in developing countries (von Braun, and Torero, 2008; von Braun et al., 2009). Yet others have warned against heavy dependence on state or international organizations as long-term solutions and underlined the crucial role of the private sector in providing adequate market mechanisms to address at least the predictable component of price variability (Jayne, Zulu, and Nijhoff, 2006).

Part of the ambiguity around this policy debate may arise because of insufficient evidence based on rigorous empirical analysis, often due to the lack of adequate data and modelling techniques for developing countries (Kalkuhl, von Braun, and Torero, 2016). In this paper we provide new empirical evidence to inform this debate by addressing the issue of price uncertainty and how it affects price levels of a staple food grain in a developing country. We do this first by distinguishing between price volatility and price uncertainty, as has been emphasized by several authors (Dehn et al., 2005; Chapoto and Jayne, 2009; Minot, 2014). Price volatility is an inherent aspect of agricultural commodity prices due to the seasonality of agricultural production and its dependence on weather (Tomek and Myers, 1993). Some price fluctuations are expected and are incorporated into the decisions made by consumers (through consumption smoothing mechanisms, provided there are no severe credit constraints (Dehn et al., 2005)) and market players (through intra-year seasonal arbitrage). For example, intra-annual seasonal variations in agricultural prices are often considered predictable due to the fixed nature of cropping periods. Similarly, post-harvest price movements due to realized crop supply changes are also largely predictable. On the other hand, price uncertainty is a form of volatility that is unpredictable or in excess of expected fluctuations; it is likely to have more severe adverse consequences for consumers and market players (Dehn et al., 2005). Relatedly, some scholars have argued that it is not price *volatility*, but rather unusually high price *levels* that hurt the most vulnerable because a majority of the poor, especially in low-income countries, are net-buying consumers of food products, and excess price fluctuations in food may lead to irreversible adverse effects (such as malnourishment and starvation) (Myers, 2006). On the other hand, net-selling farmers are relatively well-off and stand to gain from a sudden spike in prices (Barrett and Bellemare 2011; Magrini et al., 2017). Furthermore, Bellemare (2015), in an analysis of international prices and social unrest around the world, provided causal evidence that high mean food prices, and not food price volatility, led to social unrest during the 1990-2011 time-period.

Price uncertainty is likely to affect economic agents who make investment decisions prior to prices being fully revealed. This includes producers, traders, and processors of food products. According to the Conditional Asset Pricing Model (CAPM), agents who invest in risky assets expect to be compensated with higher returns, thus driving up the margins of the agents (Sharpe, 1964; Lintner, 1965).[52] The increase in margins may occur either by increasing the sales price of the product, or by decreasing its purchase price, or both. The former is likely to lead to higher

[52] This model has been tested for several agricultural commodities in the US (e.g., Brorsen et al. (1985) for wheat; Brorsen, Chavas, and Grant (1987) for rice; Schroeter and Azzam (1991) for pork; Holt (1993) for beef; and Jayne and Myers (1994) for international wheat markets of US and Japan).

consumer prices and the latter to lower producer prices, thus having adverse impacts on the welfare of consumers and producers. A common method to test the CAPM is to test if measures of price uncertainty of products affect their price levels. In this paper, we conduct this test in the context of maize products in urban Zambia, using an improve methodology (described below) that, to our knowledge, has not been previously applied to the analysis of food prices in a developing country context.

In developing countries, high food price volatility (and uncertainty) may arise for several reasons. Some developing countries may be pre-disposed to high fluctuations in food prices due to their relatively large dependence on a single staple crop, large inter-annual variations in domestic grain production, and barriers to international trade due to land-locked status, poor infrastructure, and lack of foreign exchange reserves (Byerlee et al., 2006). The poor domestic infrastructure and incomplete markets in many rural areas of developing countries tend to exacerbate seasonal variation in prices of agricultural commodities in these locales, leading to price fluctuations that are much greater than those found in international prices for the same products (Gilbert, Christiaensen, and Kaminski, 2017). Highly unpredictable and discretionary government intervention in food markets has been suspected to further exacerbate price volatility in developing regions such as sub-Saharan Africa (SSA) (Chapoto and Jayne 2009; Tschirley and Jayne, 2010; Jayne 2012). It has also been noted that the unpredictability of prices in countries in SSA could potentially make food markets very risky and inhibit the investment and participation of private players (Jayne, Zulu, and Nijhoff, 2006; Jayne 2012.) However, rigorous empirical evidence to confirm this assertion has been scarce. d'Hôtel, Le Cotty and Jayne (2013) compute a measure of "trade policy inconsistency" and find that increased inconsistency in trade policy increased the unpredictability of maize prices in Kenya. Using a laboratory experiment, Abbink, Jayne, and Moller (2011) found a very small positive but statistically insignificant impact of rules-based government policies (as opposed to discretionary and ad-hoc government action to address food price volatility) on private traders' participation in markets. The setup of a laboratory experiment may not adequately reflect the constraints and opportunities faced by the participants of the market and more analysis based on market data is warranted. Several previous assessments of food price uncertainty in developing countries of SSA have focussed largely on understanding the effects of liberalization on food price levels and uncertainty (e.g., Shively (1996) for Ghana; Barrett (1997) for Madagascar; and Karanja, Kuyvenhoven, and Moll (2003) for Kenya; Kilima et al. (2008) for Tanzania).[53] There is scope for conducting such an analysis with a focus on the key argument of the CAPM.

We test the CAPM claim that an increase in price uncertainty affects mean price levels by conducting a reduced form analysis of equilibrium prices of maize products in urban Zambia.[54,55] The maize markets of Zambia provide a reasonable context for such an analysis. Firstly, Zambia fits the criteria laid out by Byerlee et al. (2006) for being susceptible to highly variable food prices, as it is a land-locked country with heavy dependence on maize as the dominant staple, has poor infrastructure in most rural areas, and there is wide variation in crop harvests from year to year, largely as a result of variation in annual rainfall levels (Burke, Jayne, and Chapoto, 2010; Mulungu, et al., 2021). Moreover, maize is a politically and economically important crop in Zambia, thus its market is susceptible to government intervention for political gain (Chapoto et al., 2015).

We consider a risk averse representative firm in the maize value chain. According to the mean-variance framework of expected utility for a risk-averse agent, the expected utility of a value chain player is positively related to the mean and negatively related to the variance of its profit (Brorsen et al., 1985). The profit depends on the prices of outputs and inputs and subsequently influences the quantity of the maize product that the firm supplies to the market. It is expected that high variance in output prices is likely to lead to undersupply of the product to consumers and thus lead to higher equilibrium output prices. Similarly, it will lead to reduced demand for the inputs by traders, wholesalers, and processors of maize and thus depress their equilibrium prices. Brorsen et al. (1985) argue theoretically and show in the context of US agriculture that market players tend to transfer the price risk emanating from highly volatile prices to producers via lower producer

[53] The results from these studies vary considerably. For example, both the mean and uncertainty of food prices were found to increase post liberalization in case of Madagascar (Barrett, 1997) and Tanzania (Kilima et al. (2008). While a general decline in prices with increased uncertainty was observed in Ghana (Shively (1996)) and Kenya (Karanja, Kuyvenhoven, and Moll (2003)).

[54] It would be ideal to conduct a structural study including information on prices as well as demand and supply of maize products. However, this was not possible due to lack of long term time series data on demand and supply of maize.

[55] The choice of urban prices, with a focus on the capital city, Lusaka, was based primarily on availability of a long-term price series of maize products. (Lusaka is the largest city and maize market in Zambia.) Such price data are not available for rural Zambia. It is worth noting that urban maize markets differ from rural maize markets in Zambia. The urban markets consist of a large number of formal and informal wholesalers, traders, millers, retailers (including supermarket chains) and urban consumers. The rural markets also have formal and informal wholesalers, traders, millers and retailers. However, they also consist of maize producers. Many poor rural producers in Zambia are net-buyers of maize (i.e., they buy more maize than they sell). Rural consumers of maize may also buy it directly from other farmers in their community (Sitko and Kuteya, 2013). Our focus throughout this paper is on the urban maize markets of Zambia.

prices and to consumers via higher retail prices. Highly variable input prices are also likely to lead to undersupply of the output, and thus higher output prices. The likely effect of high variance of input prices on mean input price levels is more ambiguous. On one hand, it may lead to lowered demand for the input and thus lower prices. On the other hand, the existing literature suggests that high price variability of own prices leads to higher mean prices because the agent demands a risk premium for bearing the price risk (Brorsen, Chavas, and Grant (1987); Schroeter and Azzam (1991); Holt (1993)). These arguments can be condensed into the following four testable hypotheses. High price uncertainty of the output (here, retail maize products): (i) raises the price level of the output, and (ii) lowers the price level of the input (here, wholesale maize grain)[56]. On the other hand, high price uncertainty of the input (here, wholesale maize grain) leads to: (iii) higher price levels of the output (here, retail maize products), and (iv) has an ambiguous effect on the price levels of the input. The effect in (iv) is expected to be positive if traders and wholesalers demand compensation for investing in a risky commodity. On the other hand, it is expected to be negative if demand for the input (wholesale maize grain) falls very low due to its uncertain prices. The two opposing forces may also cancel each other out leading to a zero net effect. We test these hypotheses through time series analysis of prices of the following maize products for the province of Lusaka in Zambia: wholesale maize grain, retail maize grain, retail roller meal, and retail breakfast meal.[57]

Our study makes the following contributions to literature. First, we evaluate whether price risk emanating out of highly unpredictable prices is transferred to consumers (in the form of higher purchase prices for retail maize products) and producers (in the form of lower wholesale prices for maize grain). To the best of our knowledge, such a study has not been conducted for any developing country in SSA. We employ a Vector Autoregressive-Generalized Autoregressive

[56] Ideally, we would use producer prices as the price of the input. However, long term and high frequency (monthly) producer prices of maize grain are not available and are thus excluded from our analysis. Instead, we use wholesale maize prices as the input prices and proxies for the prices received by farmers.

[57] In Zambia, maize is widely consumed in the form of a thick porridge known as *nshima*. The most commonly used processed maize flour for cooking *nshima* is the so-called breakfast meal. It is made from "dehulled, soaked, degermed, and dried maize grain" (Ekpa et al., 2019, p. 623). It has the longest shelf life of the maize meal types available in Zambia and is easy to cook, but its nutritional quality is inferior to other types of maize meal. Roller meal is another popular type of maize flour obtained from dehulled maize from which only part of the germ and bran has been removed (Ekpa et al., 2019). Mugaiwa is the third form of maize meal consumed in Zambia. It is produced at hammer mills – small-scale custom maize mills found throughout the country – by directly grinding maize grain to a flour and leaving no by-product. It is known to be nutritionally superior to and less expensive than both roller and breakfast meal (Mwiinga et al., 2002).

Conditional Heteroscedastic (1,1)-in-mean (VAR-GARCH(1,1)-in-mean) approach to conduct this analysis. The VAR structure allows us to capture the co-movements between prices of closely related commodities. This is an improvement in specification of the price mean model that allows the econometrician to better isolate the truly unpredictable price variations from the predictable ones. To the best of our knowledge, the VAR-GARCH(1,1)-in-mean approach has not been applied to study food prices in a developing country context before. Finally, the study adds to the thin literature on time series analysis of food prices in SSA in general and Zambia in particular, where government intervention in maize markets is known to be highly ad-hoc and discretionary and likely to influence equilibrium maize prices.

3.2 Background of Zambian Maize Markets

The maize markets of Zambia can be divided broadly into a formal and an informal sector. The formal sector consists of commercial and well-capitalized large farmers, wholesale traders, miller/processors, and supermarket chains, and largely caters to urban consumers. The informal sector consists of a vast network of smallholder net-selling maize farmers, small-scale assembly traders and wholesalers, poor urban consumers, and a large number of rural net-buying farmer consumers who directly buy maize products from other farmers, small traders, hammer mills, and informal retail markets.[58] Zambia's maize strategic reserve and marketing board, the Food Reserve Agency (FRA), is another important market player that has exerted varying but significant amounts of influence on Zambia's maize markets (Sitko and Kuteya, 2013).[59]

Since economic liberalization in Zambia was initiated in 1991, successive government regimes have repeatedly committed to reducing intervention in agricultural markets but have fallen short of meeting the commitments and successfully completing the process of liberalization. For example, according to Chapoto and Jayne (2009), the liberalization of maize markets faced several roadblocks during the early 1990s, such as maize shortages due to drought, an appreciating local currency, and high interest rates. To combat successive food crises, the government imposed export bans, imported grain and sold it at subsidized prices to select maize millers, and set up the

[58] Maize farmers in Zambia may both sell and buy maize. A 'net-selling' farmer sells more maize than s/he purchases, and a 'net-buying' farmer purchases more maize than s/he sells.

[59] The FRA was established in 1996 as a strategic grain reserve. It had relatively limited intervention in the maize markets up until the 2001/02 maize marketing year. Between 2002 and 2015, the FRA gradually expanded its role in the maize markets, establishing itself as a major market player. During this time the FRA purchased maize directly from farmers at a pan-territorial/pan-seasonal price and sold it to select millers at a subsidized price (Mason and Myers, 2013; Sitko and Kuteya, 2013). Since 2015, the FRA's intervention in maize markets has been limited, largely due to lack of funding (Mulenga et al. 2019).

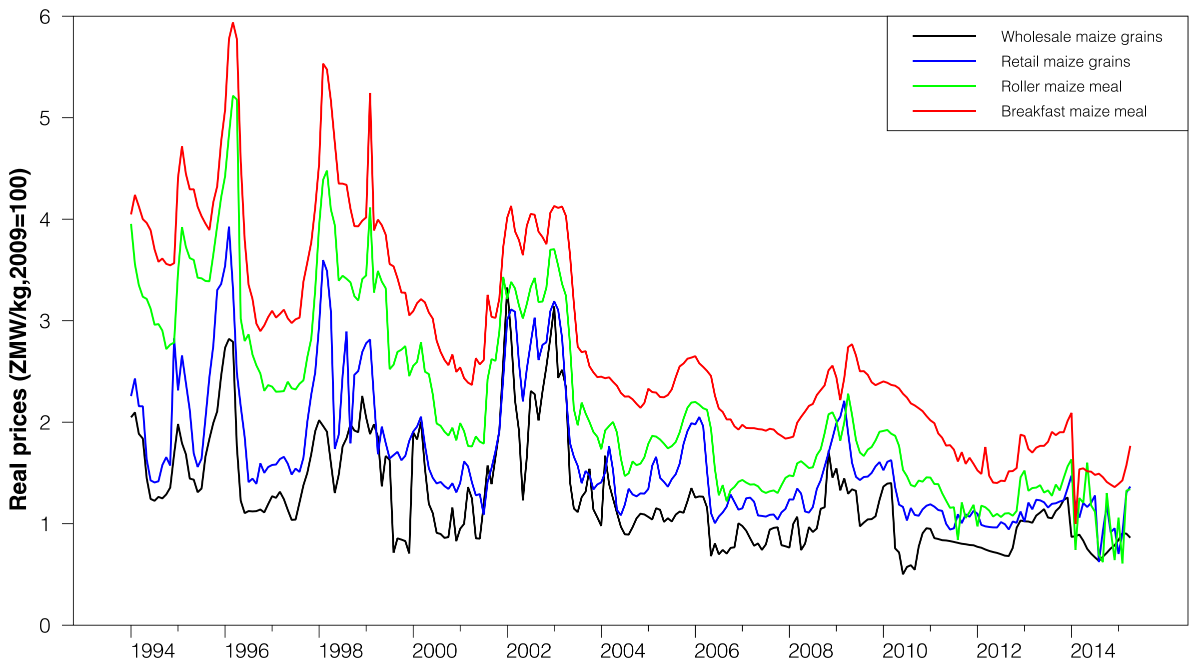
FRA. The government's well-intentioned but ad-hoc and unpredictable actions created much uncertainty in the markets. During the 2000-2003 time period, a highly uncertain market situation prevailed due to maize shortages, delayed maize imports by the government, and inaction by the private sector due to anticipated depression of prices following government imports. The delayed imports finally arrived with the next season's harvest, depressing maize prices to unanticipated levels. This led to extreme price fluctuations in the country.

A similar situation arose during the 2008/09 maize marketing year due to a larger than usual scale of purchases by the FRA at a much higher price than the prevailing maize market price (Chapoto and Jayne, 2009). The FRA continued expanding its maize purchases over the next few years with it acquiring up to 80% of the country's smallholder maize production during the 2010/11 marketing year (Mason and Myers, 2013). This period was also associated with widespread maize meal shortages and extreme price spikes in maize grain and meal (Chapoto et al., 2015).

Similarly, during the 2000s, the government continued allocating import licences preferentially and supplying grain to select millers at subsidized prices, but this subsidy was not proportionately passed on to consumers (Kuteya and Jayne, 2011). More recently, Zambia has emerged as a major surplus producer of maize in the Southern and East African region. The country was in a favorable position to export maize to neighboring countries without affecting its food security on several occasions (for example, during the 2014/15 and 2015/16 maize marketing years), yet the opportunity was not adequately taken advantage of due to ad-hoc export bans (Chisanga and Chapoto, 2015, 2016; Chisanga et al., 2017). Private market players admit that they could not compete with the high prices being offered by the FRA to farmers and the subsidized prices at which maize was being sold to select millers. Large commercial farms shifted cultivation to soybeans to avoid the uncertain maize prices. Increased sales to the FRA by smallholder farmers led to centralization of the country's maize stocks and reduced the availability of maize grain in rural Zambia (which many poor households rely on and hand pound or have custom-milled into maize meal at hammer mills) (Sitko and Kuteya, 2013).

Despite these obstacles, a vibrant private maize market emerged in Zambia post-liberalization. It has played important roles in ensuring food security for both urban and rural consumers, and in providing crucial services to small producers in remote rural areas (Chamberlin et al., 2014; Sitko and Jayne, 2014). Real maize prices have trended downward over the last two decades (Figure 1) (see also Mason et al., 2011) and margins between wholesale and retail products have narrowed during the 2000s (Kuteya and Jayne, 2011). However, there is suggestive evidence that these margins increased again after the FRA scaled up its purchases in 2010/11 and beyond (Chisanga et al., 2015).

Figure 3. 1: Real prices of maize products at Lusaka, Zambia (Jan 1994-April 2015)



Government interventions in food markets can often be well intentioned attempts to address an emerging food crisis that markets are not as well equipped to manage. However, without long term systemic improvements in the enabling environment of food markets, such crisis management is likely to further hamper the development of well-functioning and robust markets. For example, while the FRA's actions have been known to stabilize maize prices at a higher than market level (Mason and Myers, 2013), it is quite probable that the decrease in price variability has occurred by reducing intra-seasonal price variations through FRA's pan-territorial pan-seasonal pricing and selling back at subsidized prices, while creating uncertainty that adversely affects many market players (Tschirley and Jayne, 2010; Jayne 2012).

3.3 Methodology

A well accepted method to analyze price uncertainty in the time series context is through the computation of conditional volatility of prices in a GARCH framework (Engle, 1982; Bollerslev, 1986). Conditional volatility refers to the component of volatility conditional on past information on expected changes in prices (such as seasonal price variations, realized changes in prices of own and related goods in the previous period, etc.). GARCH involves simultaneously computing the one period ahead expected price mean and conditional volatility. The GARCH-in-mean approach is its slightly modified version in which the expected mean prices are allowed to depend on the conditional volatility (Engle, Lilien, and Robins, 1987). This approach has been applied as a test of the Conditional Asset Price Model (CAPM) that we use to motivate our analysis (Bollerslev, Engle, and Wooldridge, 1988). In the agricultural context, the CAPM and its application through GARCH-in-mean has been used to measure the risk premia demanded by market players for bearing the price risk while they transport, process, or store a commodity (Holt, 1993; Jayne and Myers, 1994; Kilima et al., 2008).

We estimate a multivariate GARCH-in-mean model to test whether price uncertainty of one commodity affects the price levels of other commodities. Ideally, we would prefer to estimate a model with prices of all four maize products simultaneously. Unfortunately, the estimation failed to converge for a system of more than two commodities at a time. Thus, we adopted an approach of testing two commodities at a time. The analysis was conducted for the prices of the following product pairs: (i) wholesale maize grain and retail maize grain; (ii) wholesale maize grain and retail roller meal, and (iii) wholesale maize grain and retail breakfast meal.

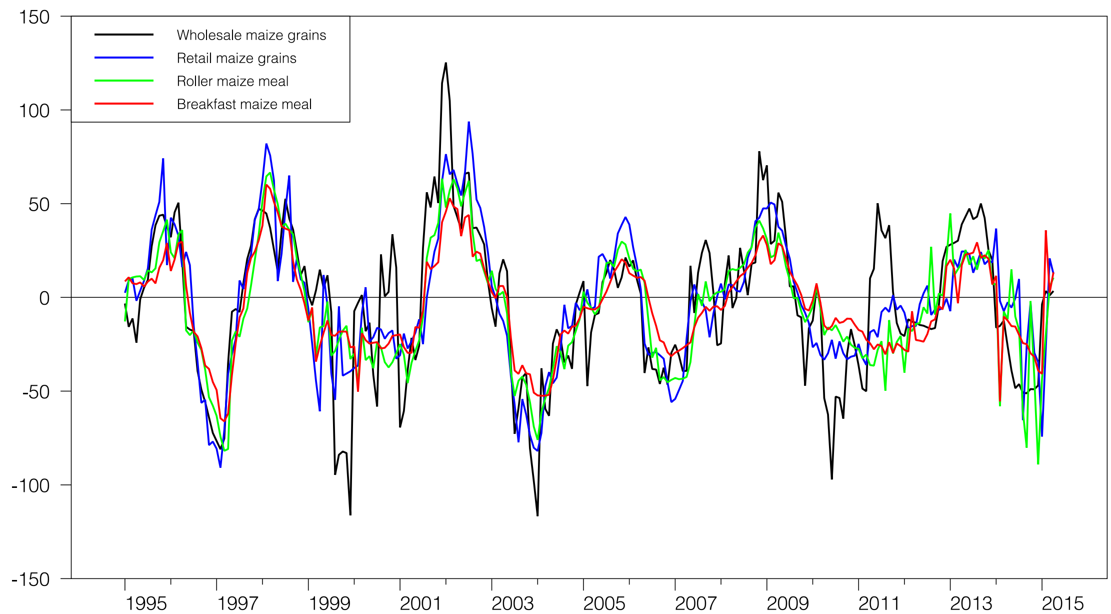
The GARCH analysis requires the dependent variables to be mean stationary. We tested each of the four price series for non-stationarity using the Dickey-Fuller test (Dickey and Fuller, 1981).[60] We are unable to reject at the 5% level the null hypothesis of the presence of a unit root in all series against the alternative hypothesis of no unit root; this implies that the series are non-stationary. Thus, we transform the price levels to their annual returns. The annual returns are computed as follows: $AR_j = 100 * ln\left\{\frac{p_{j,t}}{p_{j,t-12}}\right\}$. Here, AR_j is the annual return from series *j*, and $p_{j,t}$ and $p_{j,t-12}$ are the prices of maize product *j* in months *t* and *t-12*, respectively. Computing annual returns allows us to remove the trend as well as the seasonal component from the series.[61]

[60] We are concerned with the stationarity in mean only. The series are likely to show non-stationarity due to autocorrelation and heteroscedasticity. We check and correct for any autocorrelation in the mean model using a Vector Autoregression. Heteroscedasticity is an underlying assumption for a GARCH series, thus does not need to be corrected. The Dickey-Fuller test was considered adequate to check for non-stationarity in recent papers that employ GARCH to agricultural prices (Yang, Haigh, and Leatham, 2001; Kilima et al., 2008).

[61] Other recent papers that use annual differencing to remove seasonality from agricultural data are Otu et al. (2014) and Divisekara et al. (2021). The use of monthly dummies to control for seasonal variations in agricultural prices is much more common historically but has been criticized recently for leading to biased estimates when the time series

Transforming the data to its logarithm form helps reduce the variability and presence of outliers. Finally, the data is scaled by 100 because the original returns are often too small in magnitude and lead to computational errors (Doan, 2018). We reject at the 1% level the null hypothesis of the presence of a unit root in all of the annual returns (Table 3A.1 in Appendix 3A). Figure 2 shows the annual returns computed from the real price data.[62]

Figure 3. 2: Annual returns of maize products at Lusaka, Zambia (Jan 1995-April 2015)



Based on Figures 3.1 and 3.2 above as well as a previous study (Chisanga et al., 2015), it is likely that these pairs of variables are strongly contemporaneously correlated with each other. In such a case, the mean price model is better defined through a Vector Autoregression (VAR) as introduced by Engle and Kroner (1995) and subsequently applied by several authors in a variety of fields.[63] We compute the Autocorrelation Function (ACF) and Partial Autocorrelation Functions (PACF) of the annual returns of each series to determine the suitable lag length for the VAR. The ACFs are found to be decaying gradually over time, while the PACFs are not statistically different from zero after controlling for the first lag (Figure A1 in the Appendix). These patterns reveal that

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is short (<40 years) and seasonality is not well-defined, i.e., the assumption of deterministic monthly effects is not followed (Gilbert, Christiaensen, and Kaminski, 2017).

[62] The annual returns computed here practically translate to annual percentage changes in prices. A percentage increase (decrease) in price returns implies an increase in price levels (decrease). Thus, we are able to test our hypotheses (which focus on price levels and not returns) using the annual returns.

[63] A few recent and widely cited examples are: Beirne et al. (2010), Caporale, Ali, and Spagnolo (2015), and Caporale, Spagnolo, and Spagnolo (2016). We follow these closely for our own specification.

the series are generated by an autoregressive in lag one process (AR(1)) (Hamilton, 1994). Thus, a VAR(1) process is considered adequate for our analysis.

The specification of our model is as follows:

$$\begin{bmatrix} y_{1,t} \\ y_{i,t} \end{bmatrix} = \boldsymbol{\alpha} + \boldsymbol{\beta}' \begin{bmatrix} y_{1,t-1} \\ y_{i,t-1} \end{bmatrix} + \boldsymbol{\lambda}' \boldsymbol{X_{t-1}} + \boldsymbol{\gamma}' \begin{bmatrix} h_{11,t} \\ h_{ii,t} \end{bmatrix} + \begin{bmatrix} \epsilon_{1,t} \\ \epsilon_{i,t} \end{bmatrix} \ldots (1a)$$

$$\epsilon_t | \, \boldsymbol{I_{t-1}} \sim N(0, \boldsymbol{H_t}) \ \ldots (1b)$$

$$vech(\boldsymbol{H_t}) = \begin{bmatrix} h_{11,t} \\ h_{i1,t} \\ h_{ii,t} \end{bmatrix} = \boldsymbol{C} + \boldsymbol{A}' \begin{bmatrix} \epsilon_{1,t-1}^2 & \epsilon_{1,t-1}\epsilon_{i,t-1} \\ \epsilon_{i,t-1}\epsilon_{1,t-1} & \epsilon_{i,t-1}^2 \end{bmatrix} + \boldsymbol{B}' \begin{bmatrix} h_{11,t-1} & h_{1i,t-1} \\ h_{i1,t-1} & h_{ii,t-1} \end{bmatrix} \ldots (1c)$$

where $y_{1,t}$ and $y_{i,t}$ are the annual returns of wholesale maize grain and the *i^th^* retail maize product, respectively, observed at each month *t* (*i*=2 for retail maize grain, =3 for retail roller meal, and =4 for retail breakfast meal). $y_{1,t-1}$ and $y_{i,t-1}$ are their corresponding first lags. $\boldsymbol{X_{t-1}}$ is the vector of lagged exogenous variables that are included in the mean model. These include monthly rainfall, electricity tariff rates, prices of substitute (rice) and complement (beans) goods, and wages. $h_{11,t}$ and $h_{ii,t}$ are the conditional variances of the prices of wholesale maize grain and the i^{th} retail maize product, respectively. $\epsilon_{1,t}$ and $\epsilon_{i,t}$ are error terms that are independently and identically distributed bivariate normal with conditional variance represented by $\boldsymbol{H_t}$.[64]

$\boldsymbol{H_t}$ is the 2*2 matrix of conditional variance-covariance terms for each pair of price series. We follow Bollerslev, Engle, and Wooldridge (1988) and specify the conditional variance equation in the diagonal vech form. This reduces the number of free parameters to be estimated. This involves converting the matrix $\boldsymbol{H_t}$ to its vech form, i.e., a vector that retains only the lower portion of the symmetric matrix, and assuming that the parameter matrices $\boldsymbol{A}$ and $\boldsymbol{B}$ are diagonal. $h_{11,t}$, $h_{i1,t}$, $h_{ii,t}$ are, respectively, the conditional variance of wholesale maize returns, the conditional covariance of returns of wholesale maize and the i^{th} retail maize product, and the conditional variance of the i^{th} product's returns. $\epsilon_{1,t-1}^2$, $\epsilon_{i,t-1}^2$, and $\epsilon_{i,t-1}\epsilon_{1,t-1}$ are lagged squared residuals and lagged cross products of the residuals from the conditional mean equation. $h_{11,t-1}$, $h_{i1,t-1}$, and $h_{ii,t-1}$ are the lagged conditional variance and covariance terms.

The parameters of the mean equation (1a) consist of the vector of constant terms $\boldsymbol{\alpha}$= (α_1, α_i); the parameters on the VAR terms $\boldsymbol{\beta}$= (β_{11}, $\beta_{1i}|\beta_{i1}$, β_{ii}); the parameters associated with

[64] This implies that $E[\boldsymbol{\epsilon_t}] = \boldsymbol{0}, E[\epsilon_{1,t}, \epsilon_{1,s}] = 0$, and $[\epsilon_{1,t}, \epsilon_{i,s}] = 0$ for $t \neq s$.

the exogenous variables $\boldsymbol{\lambda}$ =($\boldsymbol{\lambda_1}$, $\boldsymbol{\lambda_i}$); and the parameters of the GARCH-in-mean terms $\boldsymbol{\gamma}$ = (γ_{11}, γ_{1i}| γ_{i1}, γ_{ii}). The parameters of the variance equation (1c) comprise of the constant terms $\boldsymbol{C}$= (c_{11}, c_{i1}, c_{1i}); the parameters on the past squared residuals and cross products of the residuals $\boldsymbol{A}$=(a_{11}, a_{12}| $0, a_{22}$); and the parameters on the past conditional variances $\boldsymbol{B} = (b_{11}, b_{12}|0, b_{22})$. The system of equations is estimated via maximum likelihood using Estima's RATS software.

Testing our hypotheses entails testing: if (i) γ_{ii} is positive (an increase in price uncertainty of the retail product is associated with an increase in the price returns of the retail product); (ii) γ_{1i} is negative (an increase in price uncertainty of the retail product is associated with a reduction in wholesale maize grain price returns); (iii) γ_{i1} is positive (an increase in price uncertainty of wholesale maize grain is associated with an increase in the price returns of the retail product); and (iv) the sign of γ_{ii} is ambiguous (an increase in price uncertainty of wholesale maize grain may have a positive or negative effect on its own prices). Wholesale maize grain prices may increase if wholesalers expect compensation for bearing the price risk due to uncertain prices. Wholesale maize grain prices may fall if the demand for wholesale maize grains falls as a result of high uncertainty in its prices. The net effect may also be nil due to these opposing forces.

All our results are to be interpreted as associations between the variables of interest. Particularly, the conditional variance and the conditional mean terms are determined simultaneously and thus we cannot conclude that one leads to the other, but simply that the occurrence of one is associated with the occurrence of the other.

3.3.1 Robustness checks

As mentioned above, we convert each price series to its annual returns to address the issues of seasonality and non-stationarity. However, this may lead to the following issues that can affect our results. Firstly, the GARCH analysis is traditionally conducted with high-frequency data in order to capture sudden changes in a time series. Thus, the use of monthly, weekly, or daily returns is more common. It is possible that we are unable to capture such sudden price movements when using annual returns. Secondly, using annual returns complicates the interpretation of our results. Since our dependent variable is now a percentage change in prices relative to 12 months prior prices, we are practically measuring the effect of conditional volatility of percentage annual price changes on the percentage annual change in price. These estimates are not necessarily the same as those obtained with percentage change in monthly prices. Finally, using the annual returns can introduce a 12th order serial correlation in the data and violate the assumption of no correlation in the error terms. In order to alleviate some of these concerns we attempt to conduct a robustness check using monthly returns and address price seasonality by introducing monthly dummies. Unfortunately, our bivariate models fail to converge in all cases except for the analysis of monthly returns of wholesale and retail maize. To provide some additional support to our results, we therefore also conduct univariate analysis of the monthly returns of each maize product.

3.4 Data

The key variables used in this study and their associated data sources are summarized in Table 3.1. Monthly wholesale maize grain price data for January 1994 through March 2015 were obtained from Zambia's Agricultural Marketing Information Centre (AMIC) of the Zambia Ministry of Agriculture and Cooperatives (now the Zambia Ministry of Agriculture). AMIC stopped collecting these data after March 2015, which is the reason our time series ends in March 2015. Monthly retail maize grain, roller meal, and breakfast meal price data were obtained from Zambia's Central Statistical Office (CSO). The CSO collects these retail prices each month from major district administrative units in Zambia. All maize grain and maize meal price data are provincial monthly averages for the province of Lusaka.[65] In addition, the following variables were used as exogenous variables in estimating the expected one period ahead prices of maize products: monthly national average rainfall, electricity prices (which are regulated by the government), the monthly provincial average prices of rice (a common substitute for maize in Zambia) and beans (a commonly consumed complementary food item with maize), and a weighted average wage rate for formal sector employees.[66]

Monthly lagged rainfall is included to capture speculative behavior that may arise due to anticipated future maize harvests (e.g., in case of poor rainfall, wholesalers and processors may anticipate a poor harvest and high prices in the future and thus store excess maize grain/maize meal now). Electricity is the primary energy source for powering large commercial maize mills in Zambia, thus we include electricity prices.[67] Rice and bean prices are included to capture the

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[65] Monthly prices for the district of Lusaka were also available but with several missing values. Thus, provincial averages were preferred.

[66] The data on bean and rice prices were available only up to June 2009 and for wages only up to March 2009. This affects the analytical sample when we include these variables in our analysis.

[67] In Zambia, different electricity tariffs are charged for residential and commercial customers, and for different levels of electricity consumption within each category. The electricity consumption relevant for maize meal processors would be the commercial rate. However, data on commercial tariffs for the entire period of analysis were not available. The electricity tariffs used in the analysis refer to the R1 category of residential tariffs. These are the lowest tariff rates among all categories and apply to residential use of electricity up to 300 kWh per month (Energy Regulation Board,

effects of a common complements and a common substitute on the equilibrium prices of maize.[68] Wage information is added to the analysis to capture the effect of labor costs. Ideally, we would have preferred to use wage rates for unskilled or semi-skilled workers to represent more closely the labor cost at a milling unit. However, such data at not available.

All prices were converted to their real terms using the monthly Consumer Price Index with 2009 as the base year. Descriptive statistics for all variables (and for both price levels and price returns) are reported in Table 3A.2 in Appendix 3A.

2015). Electricity supply and pricing is regulated by the government and even though the tariffs were observed at the monthly level, they often remained unchanged for several months.

[68] Although bread is a more common substitute for maize than rice, we could not use that information because of numerous missing values in the data on prices of bread and wheat flour. Similarly, diesel fuel prices are likely to affect the price of maize grain and meal. However, due to numerous missing values in the series for diesel prices, we opted to drop the variable from our analysis.

Table 3. 1: Data sources, time periods covered, and descriptions

Variable	Period (month/year)	Source	Description
Wholesale maize grain prices (ZMW/kg)	01/1994-04/2015	AMIC	Monthly provincial averages for Lusaka
Retail roller meal prices (ZMW/kg)	01/1994-04/2015	CSO	Monthly provincial averages for Lusaka
Retail breakfast meal prices (ZMW/kg)	01/1994-04/2015	CSO	Monthly provincial averages for Lusaka
Retail maize grain prices (ZMW/kg)	01/1994-04/2015	CSO	Monthly provincial averages for Lusaka
Consumer price index	01/1994-04/2015	CSO	Monthly national average with 2009 as the base year
Rainfall (mm)	01/1994-04/2015	Harris et al. (2020)	Monthly national average
Electricity prices (ZMW/unit)	01/1994-04/2015	CSO	Provincial averages for Lusaka observed monthly.
Retail dried beans prices (ZMW/kg)	01/1994-03/2012	CSO	Monthly provincial averages for Lusaka
Retail rice prices (ZMW/kg)	01/1994-03/2012	CSO	Monthly provincial averages for Lusaka
Formal sector wages (ZMW/month)	01/1994-03/2009	EE	Quarterly national average computed as a weighted average of salaries received by formal sector workers

Notes: ZMW (Zambian Kwacha), AMIC (Agricultural Marketing Information Centre, Zambia), CSO (Central Statistical Office, Zambia), QEES (CSO Quarterly Employment and Earnings Survey Reports, various years).

3.5 Results and Discussion

We now discuss the estimates of the VAR-GARCH(1,1)-in-mean of the three pairs of commodities. The models fail to converge when the prices of rice, beans, and/or wages were included in the mean model. Thus, we exclude these variables when presenting the results.

The estimates of the VAR-GARCH(1,1)-in-mean for wholesale and retail maize grain price returns are presented in Table 3.2. Estimates of the main parameters of interest are in bold. A Wald statistic was computed for each model specification and model 1 with no exogenous variables has the highest Wald statistic. Both own and cross AR terms are strongly significantly ($p<0.01$) related to the one period ahead price. The significant coefficients of the conditional variance model indicate that there is evidence of time varying volatility; thus, a GARCH type approach is suitable.

The estimated effects of increases in the conditional variances on the mean prices, our main coefficients of interest, are not statistically significant at the standard levels of significance ($p<0.1$). However, we find a very small positive effect of an increase in the conditional variance of wholesale maize grain price returns on the returns of retail maize grain prices that is significant at the 15% level (Table 3.2, model 1). This statistical significance is not robust across all model specifications (model 2 and model 3). However, given that the Wald statistic is highest for model 1, we consider this as very weak evidence in support of our hypothesis that an increase in the unpredictability of wholesale maize grain prices will tend to raise retail maize grain prices.

Table 3. 2: Estimated VAR-GARCH(1,1)-in-mean of annual returns of wholesale and retail maize grain

	Model 1		Model 2		Model 3	
	Coef	SE	Coef	SE	Coef	SE
Conditional mean equation for wholesale maize grain price returns						
Constant	-6.637	8.781	-7.215	9.814	-9.083	8.542
AR(1) [wholesale maize grain]	0.681***	0.057	0.680***	0.085	0.677***	0.072
AR(1) [retail maize grain]	0.212***	0.056	0.213***	0.081	0.216***	0.069
Conditional variance of wholesale maize grain returns	**0.017[#]**	**0.018**	**0.017**	**0.019**	**0.016**	**0.018**
Conditional variance of retail maize grain returns	**-0.006**	**0.011**	**-0.006**	**0.011**	**-0.008**	**0.011**
Lagged monthly rainfall (mm)			0.002	0.008	0.004	0.012
Lagged price of electricity (ZMW/unit, 2009=100)					0.047	0.072
Conditional mean equation for retail maize grain price returns						
Constant	-3.78	3.005	-4.006	3.265	-2.112	3.368
AR(1) [wholesale maize grain]	0.167***	0.042	0.166***	0.040	0.168***	0.041
AR(1) [retail maize grain]	0.756***	0.051	0.756***	0.047	0.750***	0.048
Conditional variance of wholesale maize grain price returns	**0.009**	**0.006**	**0.009**	**0.006**	**0.011**	**0.008**
Conditional variance of retail maize grain price returns	**-0.003**	**0.008**	**-0.003**	**0.009**	**-0.003**	**0.008**
Lagged monthly rainfall (mm)			0.002	0.008	0.002	0.008
Lagged price of electricity (ZMW/unit, 2009=100)					-0.042	0.047
Conditional variance equation						
C(1,1)	38.614	33.801	38.936	34.126	39.095	29.195
C(2,1)	89.549***	31.515	89.593***	31.502	90.388***	28.254
C(2,2)	9.73	7.051	9.778	7.245	9.892	7.471
A(1,1)	0.070	0.043	0.071	0.050	0.068	0.045
A(2,1)	0.087	0.061	0.087	0.064	0.089	0.069
A(2,2)	0.135**	0.055	0.135***	0.049	0.137**	0.060
B(1,1)	0.847***	0.097	0.846***	0.104	0.847***	0.088
B(2,1)	-0.313	0.241	-0.311	0.233	-0.310	0.247
B(2,2)	0.833***	0.066	0.832***	0.066	0.830***	0.072
No. of observations	243		243		243	
Log likelihood	-2057		-2057		-2056.1	
Wald statistic for overall significance of model	1202.6***		781.4***		636.8***	

Notes: *** p<0.01, ** p<0.05, * p<0.1, [#] p<0.15. Standard errors (SE) are robust to nonnormality in the innovations (Bollerslev and Wooldridge, 1992). The model failed to converge when prices of rice/dried beans and/or wages were included in the mean model.

The estimates of the VAR-GARCH(1,1)-in-mean of the wholesale maize grain and retail roller meal price returns are summarized in Table 3.3. Again, the model failed to converge when we included information on lagged prices of rice/beans and/or wages in the mean model. The Wald statistic is highest when lagged electricity prices are included in the mean model. This is likely because electricity is one of the important inputs in processing maize grain into maize meal. The estimates, however, remain practically unchanged across the different model specifications. The coefficients of the conditional variance model also remain highly significant.

The own AR terms for both series are again highly significant ($p<0.01$). Lagged wholesale maize grain price returns also significantly affect current retail roller meal returns. However, unlike the case of retail maize grain, the lagged roller meal returns do not affect current wholesale maize grain prices. This indicates that prices lower down the value chain (wholesale maize) are likely more influential on prices up the value chain (processed maize) than the other way round. We find no statistically significant effect of the conditional variance on the mean prices for either of the series. Thus, we do not find evidence in support of our hypothesis when considering the system of wholesale maize grain and roller maize meal prices.

Table 3. 3: Estimated VAR-GARCH(1,1)-in-mean of annual returns of wholesale maize grain and retail roller meal

	Model 1		Model 2		Model 3	
	Coef	SE	Coef	SE	Coef	SE
Conditional mean equation for wholesale maize grain price returns						
Constant	-5.174	9.084	-4.582	9.077	-5.09	8.992
AR(1) [wholesale maize grain]	0.739***	0.077	0.736***	0.091	0.731***	0.08
AR(1) [retail roller meal]	0.116	0.096	0.117	0.107	0.116	0.094
Conditional variance of wholesale maize grain price returns	**0.008**	**0.016**	**0.007**	**0.015**	**0.009**	**0.015**
Conditional variance of retail roller meal price returns	**0.005**	**0.014**	**0.005**	**0.013**	**0.005**	**0.013**
Lagged monthly rainfall (mm)			-0.005	0.013	-0.005	0.014
Lagged price of electricity (ZMW/unit, 2009=100)					-0.002	0.102
Conditional mean equation for retail maize						
Constant	-3.096	4.397	-3.081	4.76	-1.268	4.454
AR(1) [wholesale maize grain]	0.141***	0.037	0.141***	0.04	0.140***	0.037
AR(1) [retail roller meal]	0.75***	0.049	0.750***	0.054	0.749***	0.045
Conditional variance of wholesale maize grain price returns	**0.001**	**0.006**	**0.002**	**0.01**	**0.002**	**0.005**
Conditional variance of retail roller meal price returns	**0.011**	**0.017**	**0.001**	**0.006**	**0.012**	**0.013**
Lagged monthly rainfall (mm)			0.011	0.016	0.002	0.01
Lagged price of electricity (ZMW/unit, 2009=100)					-0.043	0.033
Conditional variance equation						
C(1,1)	34.769	29.5	35.54	35.035	36.257	42.797
C(2,1)	0.77	2.957	0.737	2.921	1.112	3.585
C(2,2)	72.197***	22.323	71.983***	22.451	70.815***	17.372
A(1,1)	0.067**	0.031	0.069*	0.036	0.069*	0.039
A(2,1)	0.072**	0.028	0.073**	0.031	0.073**	0.027
A(2,2)	0.273***	0.093	0.275**	0.109	0.285***	0.085
B(1,1)	0.869***	0.068	0.867***	0.086	0.865***	0.102
B(2,1)	0.933***	0.039	0.932***	0.042	0.929***	0.044
B(2,2)	0.368***	0.089	0.369***	0.099	0.368***	0.082
No. of observations	243		243		243	
Log likelihood	-2035.5		-2035.4		-2034.3	
Wald statistic for overall significance of model	3126.9***		2490.1***		4204.8***	

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors (SE) are robust to nonnormality in the innovations (Bollerslev and Wooldridge, 1992). The model failed to converge when prices of rice/dried beans and/or wages were included in the mean model.

Finally, estimates of the VAR-GARCH(1,1)-in-mean of annual price returns of wholesale maize grain and retail breakfast meal are presented in Table 3.4. This model failed to converge when lagged electricity prices were added to the mean model. Estimates from the model that included lagged monthly rainfall are included (Table 3.4, model 2); however, the Wald statistic is higher when no exogenous variables are included in the mean model (Table 3.4, model 1). The coefficients of the conditional variance equation are again highly significant.

The estimates of the VAR terms reveal that the price returns of both wholesale maize grain and retail breakfast meal are positively and significantly related to their lagged prices. Similar to the case of roller meal, retail breakfast meal price returns are also strongly significantly related to lagged wholesale maize grain returns, but wholesale maize grain returns are only weakly affected by lagged breakfast meal price returns ($p<0.1$). The conditional variance of wholesale maize grain price returns has a small positive and significant association with its own price returns. This result is only significant at the 15% level when controlling for rainfall (Table 3.4, model 2). The Wald statistic indicates that model 1 has higher predictive power than model 2 and thus, we conclude that we have weak evidence that highly unpredictable input prices (wholesale maize grain prices) are likely to raise their own price levels. This is perhaps because wholesalers will expect compensation for bearing the risk of investing in and storing maize grain. This is interesting since the same estimate was statistically insignificant in the previous models. As per Chisanga et al. (2015), retail breakfast meal prices tend to be more responsive than roller meal prices to an increase in wholesale maize grain prices.[69] Thus, it is likely that including breakfast meal prices in the VAR system adds valuable information to the model and enables us to estimate the relationship between own conditional variance and returns of wholesale maize grain more precisely.

The robustness check via the bivariate VAR-GARCH-in-mean of monthly returns of wholesale and retail maize reveals that there is no significant effect of conditional variance of any monthly return on the conditional mean of monthly returns of any of the products (Table 3A.3 in Appendix 3A). Similar bivariate models of monthly returns of wholesale maize and retail roller meal as well as wholesale maize and retail breakfast meal fail to converge. The univariate GARCH-in-mean of monthly returns of wholesale maize shows that there is a small increase in returns of wholesale maize in response to high conditional variance of the returns. However, this

[69] Chisanga et al. (2015) test for price transmission between wholesale maize grain and breakfast and roller maize meal prices in Zambia. They do not include retail maize grain prices in their analysis.

is true only at the 10% level of significance and is not robust across all specifications (Table 3A.4 in Appendix 3A). The univariate GARCH-in-mean analysis of monthly returns of retail maize and roller meal also reveals that there is no significant effect of the conditional variance on the conditional mean of the price return of these products (Tables 3A.5 and 3A.6, Appendix 3A). The univariate GARCH-in-mean model of breakfast meal failed to converge.

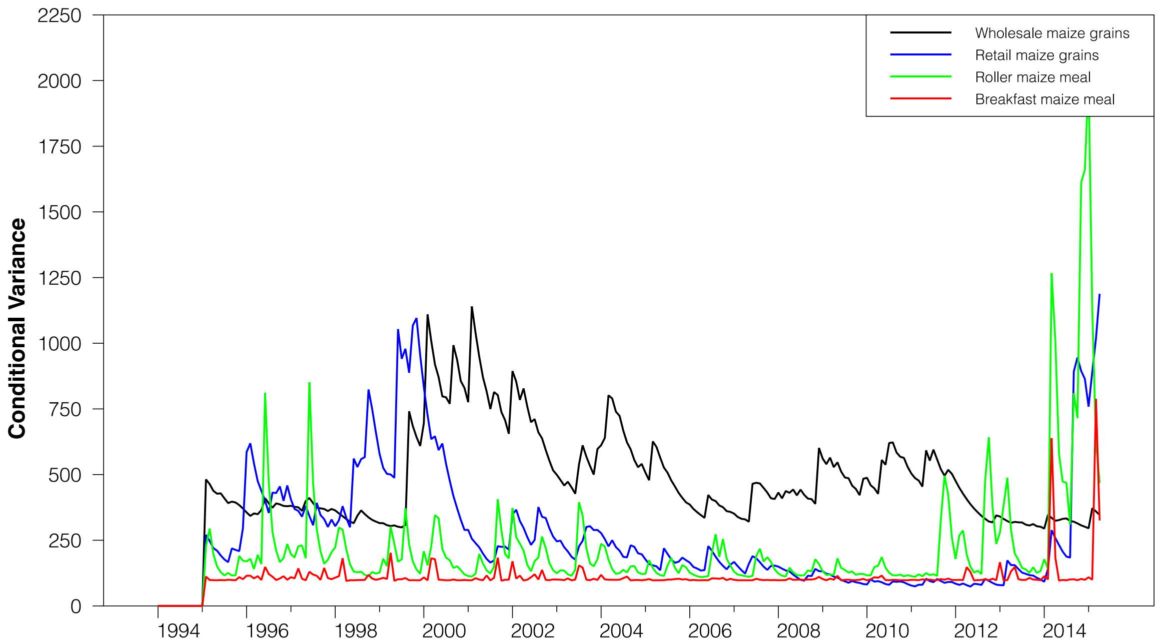
Table 3. 4: Estimated VAR-GARCH(1,1)-in-mean of annual returns of wholesale maize grain and retail breakfast meal

	Model 1		Model 2	
	Coef	SE	Coef	SE
Conditional mean equation for wholesale maize grain price returns				
Constant	-9.429	5.905	-9.743	9.662
AR(1) [wholesale maize grain]	0.769***	0.061	0.767***	0.059
AR(1) [retail breakfast meal]	0.145*	0.084	0.147*	0.08
Conditional variance of wholesale maize grain price returns	**0.019***	**0.011**	**0.019#**	**0.015**
Conditional variance of retail breakfast meal price returns	**0.011**	**0.015**	**0.008**	**0.033**
Lagged monthly rainfall (mm)			0.005	0.018
Conditional mean equation for retail breakfast meal price returns				
Constant	-2.568	1.959	-2.258	7.855
AR(1) [wholesale maize grain]	0.113***	0.027	0.112***	0.028
AR(1) [retail breakfast meal]	0.770***	0.049	0.769***	0.054
Conditional variance of wholesale maize grain price returns	**0.001**	**0.004**	**0.000**	**0.007**
Conditional variance of retail breakfast meal price returns	**0.018**	**0.031**	**0.016**	**0.059**
Lagged monthly rainfall (mm)			-0.002	0.010
Conditional variance equation				
C(1,1)	51.998	46.126	53.035	62.817
C(2,1)	123.155***	27.684	121.383***	26.591
C(2,2)	99.778***	33.29	98.650**	42.162
A(1,1)	0.073	0.049	0.074	0.061
A(2,1)	0.152***	0.029	0.158***	0.034
A(2,2)	0.095**	0.047	0.100**	0.048
B(1,1)	0.825***	0.129	0.821**	0.17
B(2,1)	-0.707***	0.218	-0.677***	0.248
B(2,2)	-0.119	0.252	-0.111	0.446
No. of observations	243		243	
Log likelihood	-1969.4		-1969.3	
Wald statistic for overall significance of model	1889.4***		1119.7***	

Notes: *** p<0.01, ** p<0.05, * p<0.1, # p<0.15. Standard errors (SE) are robust to nonnormality in the innovations (Bollerslev and Wooldridge, 1992). The model failed to converge when rice prices, dried beans prices, wages, and/or electricity prices were included in the mean model.

One concern with our specification here is distinguishing between the effects of volatility due to one product from another (for example, the volatility of wholesale maize grain price returns from the volatility of retail maize grain price returns). Since the prices are seen to move together (Figure 3.1) and vertical price transmission is reported to be high (Chisanga et al. 2015), it is likely that the price volatilities of maize products are also highly correlated. In order to assess whether this is a serious concern in our case, we conduct some additional analyses. We computed univariate GARCH(1,1) estimates of the price series of each maize product and recorded the series of conditional variances thus computed. The conditional variances are expected to be close in magnitudes to those we obtain from the full bivariate models. The time plot of the conditional variances (Figure 3.3) reveals that there is substantial variation in their values. Among the four maize products, the conditional variance of wholesale maize grain price returns is the highest through most of the years, followed by retail maize grain price returns. Retail roller and breakfast meal price returns are generally less volatile except in the recent years. This is as expected from the literature on agricultural value chains – i.e., higher volatility in agricultural output prices compared to retail prices (Goodwin and Holt, 1999; Bettendorf and Verboven, 2000; Apergis and Rezitis 2003; Ahn and Lee, 2015)). The correlation among these conditional variances is between -0.2 to 0.4 (Table 3A.7 in Appendix 3A), which further confirms that their correlation is within an acceptable range.

Figure 3. 3: Conditional variance of annual returns of maize in Lusaka, Zambia



We conducted a number of specification tests to further confirm the adequacy of our model. We conducted the Ljung-Box Q test on the residuals obtained from each of multivariate analysis to test if there is any remaining serial correlation in the mean equations. We fail to reject the null of no remaining serial correlation for 10 lags at the 5% level for all series except for retail roller meal (Table 3A.8, Appendix 3A). However, we do not modify the model in light of these results because it is important that the model represent the decision making of the market players (traders and roller meal processors). Complicating the model by adding more lags might help passing the Ljung-Box Q test but might not well represent the underlying decision making of the agents. The purpose of the mean model is to remove any correctable serial correlation. Small autocorrelation may exist but may be practically unimportant (Doan, 2018), as in the case of roller meal here where the Partial Autocorrelation of the second lag is almost zero (see Figure 3A.1 in Appendix 3A). Lastly, we conduct the McLeod-Li Q test on the squared residuals from each multivariate analysis to test for remaining GARCH effects. We are unable to reject the null of no remaining serial correlation in the squared residuals at the 5% level in all cases, thus confirming that a GARCH(1,1) specification is adequate (Appendix 3A Table 3A.4).

3.6 Limitations

We discuss several limitations in our empirical analysis that could potentially affect the quality of our estimates.

3.6.1. Non-convergence of models when including more than two maize products

The prices of maize products studied in this paper are closely related to each other and changes in one product are likely to affect the prices of the others. Thus, we would have preferred to estimate a multivariate VAR-GARCH(1,1)-in-mean system of all four commodities modelled simultaneously. However, the models failed to converge when including more than two products at a time. The short length of the time series available to us could be a reason behind this. It could also be that more sophisticated econometric techniques were needed to address issues of potential cointegration between the prices and/or shifting regimes during the study period covered in the analysis. This could be a potential area of future research to improve upon our analysis.

3.6.2. Lack of high frequency data

GARCH models are usually computed with high frequency data (daily or weekly) to be able to effectively capture the sudden unpredictable changes in the variable(s) of interest. The maize product prices used in our analysis are observed at the monthly level only, during which they could have adjusted substantially to sudden shocks in policy. For example, Chisanga et al. (2015) found that 72% of a rise in wholesale maize grain prices in Zambia is transmitted to retail breakfast meal prices within the same month. This might be one of the reasons behind the lack of significant relationships observed between the conditional variances and returns in our analysis.

3.6.3 Addressing seasonality of agricultural data

Gilbert, Christiaensen, and Kaminski (2017) have pointed out that the use of monthly dummies to capture seasonality of agricultural prices may lead to incorrect estimates, especially if the time series is shorter than 40 years and if seasonal variations are ill defined (i.e., there is substantial year to year difference in the seasonal variations). Our analysis covers only 20 years and irregular seasonality of maize prices has been reported by Chapoto and Jayne (2009). In our paper, we make an improvement from this standard practice by using the annual returns to remove the seasonal variations. However, Gilbert, Christiaensen, and Kaminski (2017) suggest several other more sophisticated methods to control for seasonality too which we were not able to implement in our analysis.

3.7 Conclusion

In this paper we study price uncertainty in four maize products across the maize value chain of urban Zambia. The objective of the study is to test whether uncertainty in prices of these products is transmitted to their price levels. We motivate our research question using the Conditional Asset Price Mechanism (CAPM) as the theoretical background. The CAPM states that agents who invest in risky assets demand higher compensation for bearing that risk. We hypothesize that high price uncertainty in wholesale maize grain prices is associated with higher prices for retail maize products (retail maize grain, roller meal, and breakfast meal); on the other hand, we expect high price uncertainty in the retail maize product prices to be associated with lower prices for wholesale maize grain. We also hypothesize that the effect of own price uncertainty is positive on own price levels for the retail products and ambiguous for wholesale maize grain.

We use a VAR-GARCH(1,1)-in-mean procedure to test these hypotheses, using monthly data from January 1994 through March 2015 that have been converted to annual price returns. We find some weak evidence ($p<0.1$) that wholesale maize price returns are positively and statistically significantly related to own price uncertainty when estimating the bivariate model of wholesale maize grain and retail breakfast meal price returns. However, this result does not hold across all model specifications. Further, this estimated effect is not statistically significant at conventional levels when wholesale maize grain price returns are jointly tested with retail maize grain or retail roller meal price returns. Wholesale maize grain and breakfast meal prices have been found to be more closely related to each other in previous studies than wholesale maize grain and roller meal prices (Chisanga et al., 2015). Thus, it is possible that the breakfast meal price returns play an important role in predicting one period ahead wholesale maize grain price returns, and thus in correctly measuring the uncertainty of wholesale maize grain price returns. The robustness check conducted through the univariate GARCH analysis of monthly returns of wholesale maize also shows weak evidence of a positive correlation between its uncertainty and level of returns; however, these results do not hold across all specifications either. Overall, we find some very weak though not robust evidence that highly uncertain prices of wholesale maize may be correlated with an increase in wholesale maize price returns.

We also find very weak evidence that uncertainty in wholesale maize grain price returns is very weakly associated ($p<0.15$) with a small increase in retail maize grain price returns. This result, however, does not hold across all specifications and nor does it hold in the robustness checks conducted using monthly returns instead of annual returns. Retail roller meal and breakfast meal price returns are not significantly affected by uncertain wholesale maize price returns. Similar results hold when we analyze monthly returns (where possibly) instead of annual returns. Overall, we do not find any evidence of statistically significant effects of highly uncertain prices of retail maize products on their own price returns or the wholesale maize price returns.

Finally, the application of a Vector Autoregression (VAR) in the mean model of the GARCH system for estimating one period ahead price returns of food products across a value chain is a methodological improvement over existing studies in similar contexts. It is highly likely that prices of a product at one level of the value chain are affected by prices at other levels of the value chain. The univariate GARCH models that have been used to study price unpredictability in developing countries in past studies ignore this aspect and thus may not be capturing important information about the price determination process.

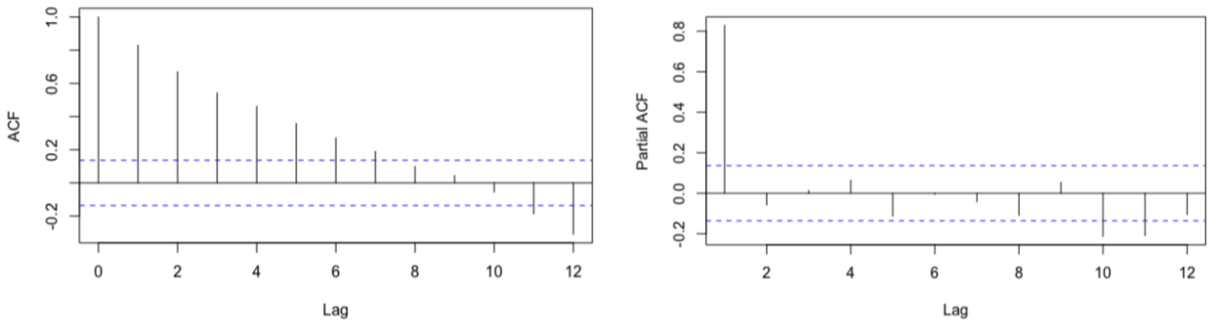
APPENDIX

Table 3A. 1: Dickey-Fuller unit root test results (H_0: There is a unit root for the series, H_1: There is no unit root for the series, the series is stationary)

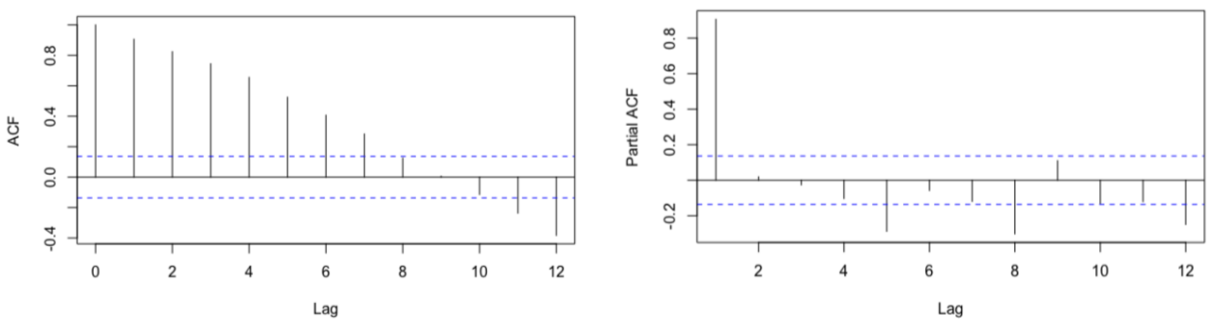
Variable	T-stat	Inference
Levels of prices of:		
Wholesale maize grain	-1.734*	Reject at 10% significance level
Retail maize grain	-1.386	Fail to reject
Retail roller meal	-1.574	Fail to reject
Retail breakfast meal	-1.226	Fail to reject
Annual returns of prices of:		
Wholesale maize grain	-4.573***	Reject at 1% significance level
Retail maize grain	-3.774***	Reject at 1% significance level
Retail roller meal	-3.873***	Reject at 1% significance level
Retail breakfast meal	-3.414***	Reject at 1% significance level

Note: Critical values of t-stat at different levels of significance: 1% (***) =-2.574; 5% (**)=-1.941; 10% (*)=-1.616.

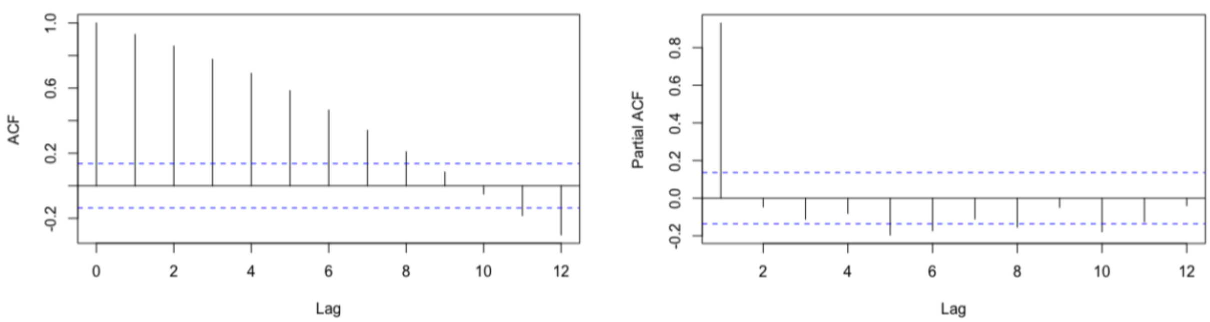
Figure 3A. 1: Autocorrelation and Partial Autocorrelation Functions of annual price returns



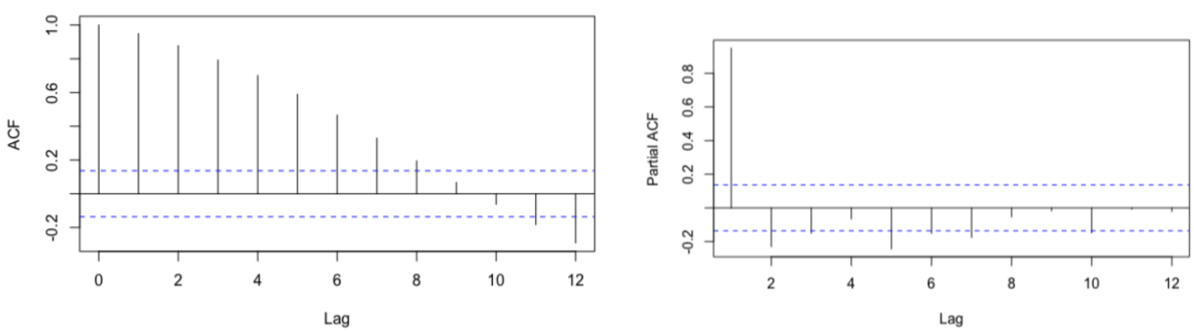
Panel A: Wholesale maize grain



Panel B: Retail maize grain



Panel C: Roller maize meal



Panel D: Breakfast maize meal

Table 3A. 2: Descriptive statistics of variables used in the analysis

Variable	N	Mean	Median	SD	Min	Max
Real wholesale maize grain price (ZMW/kg, 2009=100)	256	1.27	1.12	0.53	0.50	3.33
Real retail maize grain price (ZMW/kg, 2009=100)	256	1.65	1.46	0.63	0.62	3.93
Real retail roller meal price (ZMW/kg, 2009=100)	256	2.19	1.91	0.93	0.61	5.22
Real retail breakfast maize meal price (ZMW/kg, 2009=100)	256	2.79	2.50	1.02	1.00	5.94
Rainfall (mm)	256	82.56	34.30	91.09	0.00	287.70
Real electricity prices (ZMW/unit, 2009=100)	256	64.82	62.63	22.83	27.07	125.51
Real retail dried beans price (ZMW/kg, 2009=100)	256	10.97	10.08	2.83	6.19	20.24
Real retail local rice price (ZMW/kg, 2009=100)	186	7.80	8.32	4.20	2.54	18.92
Real formal sector wage (ZMW/month, 2009=100)	183	1570.60	1452.51	390.77	975.30	2483.34
Annual returns on wholesale maize grain	244	-3.40	-0.63	40.40	-116.68	125.32
Annual returns on retail maize grain	244	-2.88	-3.98	35.38	-90.81	93.83
Annual returns on retail roller meal	244	-5.66	-6.89	31.60	-89.09	66.59
Annual returns on retail breakfast meal	244	-4.66	-6.57	25.08	-66.12	60.19
Monthly returns on wholesale maize grain	255	-0.34	1.12	17.24	-82.35	99.05
Monthly returns on retail maize grain	255	-0.20	1.46	13.79	-72.09	58.64
Monthly returns on retail roller meal	255	-0.42	1.91	14.34	-79.08	77.93
Monthly returns on retail breakfast meal	255	-0.33	2.50	8.12	-74.05	43.18

Table 3A. 3: Estimated VAR-GARCH(1,1)-in-mean of monthly returns of wholesale and retail maize

	Coef	SE
Conditional mean equation for wholesale maize		
Constant	6.945	4.477
AR(1) [wholesale maize]	-0.025	0.115
AR(1) [retail maize]	0.08	0.115
Conditional variance of wholesale maize returns	0.008	0.010
Conditional variance of retail maize returns	0.001	0.002
January=1	-7.067	4.909
February=1	-9.189	7.92
March=1	-8.981*	5.076
April=1	-22.721***	5.624
May=1	-22.172***	5.862
June=1	-13.501	9.743
July=1	-9.937	8.117
August=1	-5.748	5.301
September=1	-6.275	5.054
October=1	-3.668	5.798
November=1	-2.684	5.435
Conditional mean equation for retail maize		
Constant	5.075*	2.17
AR(1) [wholesale maize]	0.082*	0.033
AR(1) [retail maize]	-0.029	0.071
Conditional variance of wholesale maize returns	0.002	0.004
Conditional variance of retail maize returns	-0.002	0.007
January=1	-4.049	2.424
February=1	-2.485	2.471
March=1	-3.218	2.75
April=1	-17.112***	3.001
May=1	-19.794***	2.993
June=1	-9.377***	2.625
July=1	-7.688***	2.481
August=1	0.428	2.633
September=1	-6.618*	2.633
October=1	-1.716	2.575
November=1	-2.251	3.072
Conditional variance equation		
C(1,1)	27.401	31.503
C(2,1)	9.132	8.473

Table 3A. 3 (cont'd)

C(2,2)	1.7	2.433
A(1,1)	0.155	0.237
A(2,1)	0.092	0.195
A(2,2)	0.184	0.128
B(1,1)	0.75**	0.267
B(2,1)	0.612**	0.309
B(2,2)	0.845***	0.091
No. of observations	254	
Log likelihood	-1998.3757	
Wald statistic for overall significance of model	218.28837***	

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard Errors are robust to misspecification of distribution of underlying residuals (Bollerslev and Wooldridge, 1992). The model fails to converge when either rainfall or price of electricity are introduced as exogenous variables in the conditional mean equation.

Table 3A. 4: Estimated GARCH(1,1)-in-mean of monthly returns of wholesale maize grain

	Model 1		Model 2		Model 3	
	Coef	SE	Coef	SE	Coef	SE
Conditional mean equation						
Constant	7.574	9.255	22.704***	4.549	22.488***	5.432
AR(1)	0.042	0.235	0.083	0.099	0.085	0.135
Conditional variance of wholesale price returns	0.021	0.023	0.012*	0.006	0.012	0.011
Lagged monthly rainfall (mm)			-0.106***	0.035	-0.107***	0.036
Lagged price of electricity (ZMW/unit, 2009=100)					0.004	0.051
January=1	-8.797	7.296	-0.141	5.351	-0.156	5.584
February=1	-13.159**	5.953	-3.42	5.713	-3.337	6.51
March=1	-14.374	10.983	-11.264**	5.027	-11.253*	6.078
April=1	-28.279***	8.707	-25.125***	4.962	-25.064***	6.274
May=1	-28.314***	5.157	-33.859***	5.135	-33.807***	6.293
June=1	-20.131***	5.786	-32.04***	5.788	-31.99***	5.19
July=1	-12.467***	4.642	-26.791***	5.119	-26.759***	5.506
August=1	-9.454**	4.479	-22.371***	4.567	-22.405***	4.625
September=1	-8.455	5.421	-21.15***	4.211	-21.216***	4.773
October=1	-5.242	6.68	-18.617***	4.33	-18.682***	4.646
November=1	-4.521	8.161	-14.928***	4.06	-14.983***	4.707
Conditional variance equation						
Constant	88.654**	36.406	48.544*	29.246	47.92	46.545
Lagged squared residual of mean equation	0.491	0.638	0.871*	0.528	0.872	0.94
Lagged variance term	0.256	0.225	0.263	0.126	0.266*	0.143
No. of observations	254		254		254	
Log likelihood	-1046.7		-1042.8		-1042.8	
Wald statistic for overall significance of model	6441.3***		3358.5***		2138.4***	

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard Errors are robust to misspecification of distribution of underlying residuals (Bollerslev and Wooldridge, 1992).

Table 3A. 5: Estimated GARCH(1,1)-in-mean of monthly returns of retail maize grain

	Model 1		Model 2		Model 3	
	Coef	SE	Coef	SE	Coef	SE
Conditional mean equation						
Constant	4.601**	2.007	12.892***	3.235	15.546***	3.26
AR(1)	-0.007	0.114	-0.015	0.068	-0.034	0.081
Conditional variance	-0.0005	0.006	-0.001	0.006	-0.002	0.006
Lagged monthly rainfall (mm)			-0.067***	0.017	-0.069***	0.016
Lagged price of electricity (ZMW/unit, 2009=100)					-0.039*	0.019
January=1	-3.48	2.466	2.242	3.966	2.959	2.797
February=1	-1.539	2.865	5.357	4.371	6.037*	3.068
March=1	-1.759	2.622	2.894	2.76	3.299	2.493
April=1	-16.172***	3.38	-13.117***	3.16	-12.394***	2.528
May=1	-19.43***	2.706	-24.819***	3.619	-24.879***	3.388
June=1	-9.592***	3.183	-18.232***	4.325	-18.356***	3.649
July=1	-7.415**	2.97	-16.075***	3.989	-16.109***	3.545
August=1	0.493	2.94	-8.576*	4.544	-8.54*	3.572
September=1	-5.954*	3.139	-14.042***	3.678	-13.677***	3.338
October=1	-1.228	2.778	-9.921**	4.346	-10.091***	3.763
November=1	0.858	5.163	-5.152	2.956	-5.125*	2.589
Conditional variance equation						
Constant	2.438	3.367	2.791	2.554	3.135	2.036
Lagged squared residual of mean equation	0.326	0.374	0.443	0.407	0.477*	0.242
Lagged variance term	0.748***	0.233	0.673***	0.186	0.647***	0.103
No. of observations	254		254		254	
Log likelihood	-959.4		-955.5		-953.5	
Wald statistic for overall significance of model	130.4		79.4		74	

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard Errors are robust to misspecification of distribution of underlying residuals (Bollerslev and Wooldridge, 1992).

Table 3A. 6: Estimated GARCH(1,1)-in-mean of monthly returns of retail roller meal

	Coef	SE
Conditional mean equation		
Constant	11.805***	2.095
AR(1)	-0.274**	0.127
Conditional variance	0.002	0.002
Lagged monthly rainfall (mm)	-0.025*	0.013
Lagged price of electricity (ZMW/unit, 2009=100)	-0.065***	0.018
January=1	-3.6	2.639
February=1	-3.997	2.451
March=1	-5.117***	1.611
April=1	-11.326***	1.555
May=1	-9.412***	1.523
June=1	-14.659***	2.009
July=1	-14.524***	2.317
August=1	-8.657***	1.959
September=1	-7.532***	1.861
October=1	-7.09***	2.321
November=1	-6.249***	1.851
Conditional variance equation		
Constant	9.174	6.507
Lagged squared residual of mean equation	2.508***	0.663
Lagged variance term	0.05	0.036
No. of observations	254	
Log likelihood	-941.7	
Wald statistic for overall significance of model	17.5	

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard Errors are robust to misspecification of distribution of underlying residuals (Bollerslev and Wooldridge, 1992). The model fails to converge when either rainfall or price of electricity are introduced as exogenous variables in the conditional mean equation.

Table 3A. 7: Correlation Matrix for conditional variances computed from univariate GARCH(1,1) of annual returns of each series

	Wholesale maize grain	Retail maize grain	Retail roller meal	Retail breakfast meal
Wholesale maize grain	1			
Retail maize grain	0.020	1		
Retail roller maize meal	-0.195	0.368	1	
Retail breakfast maize meal	-0.064	0.238	0.316	1

Table 3A. 8: Diagnostics for remaining autocorrelation and GARCH effects

	Ljung-Box Q stat	p-value	McLeod-Li Q stat	p-value
Wholesale maize grain-retail maize grain price returns				
Wholesale maize grain	14.499	0.106	14.903	0.094
Retail maize grain	8.736	0.462	13.441	0.144
Wholesale maize grain-retail roller meal price returns				
Wholesale maize grain	12.964	0.164	13.657	0.135
Retail roller meal	19.564	0.021	7.421	0.593
Wholesale maize grain-retail breakfast meal price returns				
Wholesale maize grain	11.790	0.225	11.884	0.220
Retail breakfast meal	15.729	0.073	0.676	0.998

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