Global Crude to Local Food: An Empirical Study of Global Oil Price Pass-through to Maize Prices in East Africa

Brian M. Dillon[a] and Christopher B. Barrett[b] *

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Abstract:

We study the transmission of global crude oil and maize prices to local maize prices across east Africa. Consistent with several recent papers, we do not find a significant causal relationship between oil and maize prices at the global market level. However, global oil prices do strongly affect maize prices at sub-national markets through their impacts on transport fuel prices. When we allow for the potential effects of local fuel prices on the price spread between maize markets, the average price elasticity of local maize with respect to global oil prices is 0.26. For 7 of the 17 markets in the study – and particularly for the 3 markets farthest from the coast – global oil prices have larger effects on local maize prices than do global maize prices. Furthermore, oil price shocks transmit much more rapidly throughout the region than do maize price shocks. This suggests that the short term effects of correlated commodity price increases on food prices in Africa may be driven more by rising transport costs than by the rising costs of food grains on global markets.

Keywords: food prices; energy prices; price pass-through; African development; agricultural markets
JEL codes: O13, Q11, F15

[a] Evans School of Public Affairs, University of Washington; bdillon2@uw.edu
[b] Charles H. Dyson School of Applied Economics and Management, Department of Economics, and David R. Atkinson Center for a Sustainable Future, Cornell University; cbb2@cornell.edu

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1. Introduction

The global food price crises of 2008 and 2011 drew widespread attention to the effects of commodity price shocks on poverty and food security in the developing world. In the ensuing debate over the causes of these price spikes, one prominent thread emphasizes the role of energy costs, particularly the price of oil (Abbott et al. 2008, Headey and Fan 2008, Krugman 2008, Mitchell 2008, Rosegrant et al. 2008, Baffes and Dennis 2013). Yet there is a notable absence of careful empirical analysis of the links between food prices and energy prices at the level where food prices most affect the poor, i.e., in markets within developing countries. Do global crude oil price shocks significantly affect local food prices, particularly in countries with high levels of subsistence food production? If so, how much, and by what mechanisms?

This paper tackles those questions, focusing on maize markets in the four major east African economies: Ethiopia, Kenya, Tanzania and Uganda. These markets are ideal for studying the food-energy link in developing economies. Maize is the main input to global biofuels production due to the reliance of the US ethanol industry on corn. Maize is the primary staple food in east Africa, serving as both the greatest source of calories and a key income generator for farmers. And the region is distant from major maize exporters and burdened with poor transport infrastructure, so that variable transport costs are potentially relevant.

Oil prices can affect maize prices through three main channels. First, higher oil prices can increase the cost of farm inputs such as inorganic fertilizer (which is made from natural gas) and fuel for tractors or pumps. Second, higher global oil prices can stimulate market demand for corn to convert into ethanol, thereby driving up maize prices on the global market, which transmit to local markets through trade linkages. Third, oil price increases can drive up transport costs, which in turn affect the prices of all traded commodities, food grains included.

The first channel is of second-order concern in the study countries, all of which are well-integrated with world maize markets and act as pure price-takers on world maize markets. For these economies, changes in production costs affect profits and output levels, but not long-run equilibrium prices. Any direct effects of higher production costs will be captured by changes in global market maize prices, which we observe and include in the analysis.[1]

The second channel rests on the premise that biofuel production creates a structural link between oil prices and maize prices. This topic has received substantial attention since the passage of the ethanol

[1] Farmer expenditure on fuel for tractors or irrigation pumps is zero for the vast majority of farmers in east Africa (and total expenditure on these inputs is negligible). Kenya is the only study country in which fertilizer application was commonplace during the study period. In Appendix C we show that, as expected, maize prices in Kenya are not responsive to changes in the price of fertilizer. In the same section we also verify that after conditioning on global market prices of maize and oil, global fertilizer prices are not an important determinant of domestic prices of maize and fuel in all of the study countries.

mandate in the US Energy Policy Act of 2005 (Krugman 2008, Mitchell 2008, de Gorter et al. 2013). However, the recent literature finds little empirical support for the hypothesis that oil price changes transmit strongly to maize prices on global markets (e.g., Zhang et al. 2007, 2009, 2010, Gilbert 2010, Serra et al. 2011, Enders and Holt 2012, Zilberman et al. 2013). We estimate a number of models relating oil and maize prices on global markets, and likewise find no evidence of a systematic, causal link. We therefore do not emphasize this channel. However, in interpreting results we do consider the case of correlated increases in global oil and maize prices. In this sense our approach is conservative, because any undetected links through biofuels markets would only amplify the effects that we find.

We focus on the third channel, the link through transport costs. Transport costs loom large in African markets, because of the low value-to-weight ratio of grains, long distances between population centers, and rudimentary transport infrastructure dependent primarily on trucks (lorries). Even though subsistence food production is still widespread in the region, significant volumes of maize are traded across space, and even across borders, in each of the study countries. The food supply to urban consumers relies heavily on lorry-based grain shipments from the domestic breadbasket regions and from international ports of entry. As we show, global oil prices exert considerable influence on sub-national maize market prices through their effects on transport fuel prices.

Using a newly assembled data set of monthly, average maize prices and monthly, average petrol prices (at the pump) from 17 sub-national markets for the period 2000-2012, we estimate the pass-through effects on local maize prices of changes in the world market prices of oil and maize. Our empirical approach involves stepwise estimation of error correction models. First, we estimate the impact of global oil and global maize price changes on petrol and maize prices in the port-of-entry (POE) markets for the four study countries. In this step we allow changes in global oil prices to impact the price margin between POE maize and global maize. Next, we estimate the equilibrium pass-through rates of petrol prices from the POE markets to other sub-national markets, to model changes in local transport costs. Finally, we estimate the equilibrium pass-through rates of maize prices from the POE markets to other sub-national markets, allowing changes in local petrol prices to directly impact the maize price spread. Following Borenstein et al. (1997), in all steps we allow for the possibility of asymmetric adjustment to price increases and decreases.

This empirical strategy rests on four key identifying assumptions, discussed in detail in Section 3. Three of these are rather innocuous: first, that study countries are price takers on global markets; second, which follows logically, that port-of-entry prices are weakly exogenous to interior market prices; and third, that domestic fuel prices are weakly exogenous to domestic maize prices. The fourth and most tenuous identifying assumption is that exchange rate changes are at least weakly exogenous to changes in the global prices of oil and maize. While we believe this to be a restrictive (but necessary) assumption in the long run, in Appendix B we show that there is evidence in support of exchange rate exogeneity in our data.

We have three main results. First, we find an important role for global crude oil prices in determining maize prices in local markets within east Africa. Across the 17 markets in our study, a 1% increase in global oil prices is associated with an average long run maize price increase of 0.26%, even in the absence of changes in global maize prices or in the exchange rate. This finding is remarkably stable across study markets; all but 2 of the 17 estimated global-to-local oil price pass-through rates lies in the range 0.10-0.41%. In comparison, a 1% rise in global maize prices, absent a corresponding change in oil prices or exchange rates, leads to a 0.42% average local maize price increase, with considerably more dispersion among markets. When global oil and maize prices simultaneously increase by 1%, the average increase in local maize prices is 0.68%. Any remaining maize price adjustments operate via the exchange rate (more on that in Sections 3 and 5). These estimated rates of price transmission are substantially greater than those in much of the current literature, which are likely biased downwards by the omission of transport costs (Benson et al. 2008, Abbott and Borot de Battisti 2011, Baltzer 2013).

Second, in the three markets that are farthest from an ocean port (Gulu and Mbarara, Uganda, and Kigoma, Tanzania), as well as in all of the Kenya markets, the elasticities of local maize prices with respect to global oil prices are equal to or greater than those with respect to global maize prices. In these land-locked areas, variable transport costs have a large and often overlooked effect on food prices, and therefore on food security. Indeed, across the sample we find that the estimated elasticity of local maize prices with respect to global oil prices is increasing in distance from the port-of-entry.

Third, because we observe local market prices for both food and fuel, we are also able to estimate the speed with which global price changes transmit to local grain prices. We find that oil price shocks transmit much more rapidly to local maize prices than do global maize price shocks. In three-quarters of the markets, increases in global oil prices transmit more than twice as rapidly as global maize price increases. This is likely because all liquid fuel consumed in the region is imported, and trade is the only way to clear the market. Maize, in contrast, is produced by tens of millions of spatially dispersed farmers, allowing for local supply adjustments and consumption out of stocks that dampen the speed of price transmission. Also, food prices are a political flashpoint. Ad hoc policy responses to mitigate food price shocks, such as export bans or releases of reserves, are not uncommon (Ivanic et al. 2012, Barrett 2013, Pinstrup-Andersen 2013). An important implication of this speed-of-adjustment finding is that when oil prices and maize prices co-move on global markets, as they often do, the immediate effect on food prices may be due as much or more to changes in transport costs than to changes in the global prices of the grains. To the extent that policymakers ignore the fuel channel and attempt to mitigate food price spikes by intervening exclusively in grain markets, policy responses may not achieve the desired price stabilization effects.

There is a large literature in economic history and development economics that deals with transport costs, but the emphasis tends to be on the fixed cost components of transport – roads, railways, etc. – and their relation to economic outcomes.[2] Here, our interest is the link between variable transport costs and the price of food in low income countries. To our knowledge this is the first paper to make use of local transport fuel prices in a study of food price determination in the developing world. While the fuel-food price connection is a frequent topic in the popular press, there is little rigorous research on this topic. This is likely due to the scant availability of data on variable transport costs (World Bank, 2009, p. 175), which we assembled from a wide range of government sources, as described below.

This paper also speaks to broader economic questions of time-varying market frictions and asymmetric price adjustment (Engel and Rogers 1996, Borenstein et al. 1997, Peltzman 2000, Evans 2003, Anderson and van Wincoop 2004). Where much of the existing literature struggles to identify the source(s) of frictions that give rise to incomplete, slow, or asymmetric price pass-through, for example in financial markets (Constantinides 1986, Anderson 1997, Michael et al. 1997), here the frictions arise naturally from observable variation in transport costs. The fact that oil prices exert a substantial influence on grain prices purely through transport costs underscores the important role that such frictions can play in market price determination.

Finally, these questions hearken back to an earlier literature in which economists worried about commodity price dynamics and global-to-local price transmission because of their impacts on developing countries, especially in Africa (Ardeni and Wright 1992, Deaton and Laroque 1992, 1996, Deaton 1999). As Deaton (1999, p.24) laments, speaking of commodity exports, “the understanding of commodity prices and the ability to forecast them remains seriously inadequate. Without such understanding, it is difficult to construct good policy rules.” The same concern applies today. In the absence of careful empirical analysis of commodity price behavior, even thoughtful commentators may misunderstand the drivers of observed price patterns, with important implications for policy.

The rest of the paper proceeds as follows. In Section 2 we describe the data and the setting. In Section 3 we outline the empirical framework. Section 4 contains the empirical results. Section 5 discusses findings and presents the cumulative pass-through elasticities. Section 6 concludes.

2. Data and Setting

[2] See, among numerous others: Fogel 1964, Chandra and Thompson 2000, Jacoby 2000, Limão and Venables 2001, Baum-Snow 2007, Jacoby and Minten 2009, Atack et al. 2010, Buys et al. 2010, Bell 2012, Storeygard 2012, Donaldson forthcoming.

Background and setting

According to the 2009 FAO Food Balance Sheet data, maize is the largest source of calories in Ethiopia, Kenya, and Tanzania. In 2009 the average Ethiopian consumed 418 kcal/day of maize (accounting for 20% of total dietary energy intake), the average Kenyan consumed 672 kcal/day (32%), and the average Tanzanian consumed 519 kcal/day (23%). In Uganda, maize consumption averaged 190 kcal/day (9%), third in importance behind plantains and cassava but still critical to food security. Maize consumption in Uganda varies regionally, with greater consumption in the north and east than in the southwest.

Table 1 shows the allocation of land to maize and categories of other crops over the period 2007-2010. In Kenya and Tanzania, more land is allocated to maize than to the total of all crops in any other category. In all four countries the land area of maize cultivation is greater than that of any other single crop (not shown).[3] In Figures 1 and 2 we plot the time path of annual cultivated maize acreage and total annual maize output, respectively, for the four study countries. In Ethiopia, Kenya, and Uganda, both series show upward trends over the study period (2000-2012). In Tanzania, however, the data show a near doubling of maize acreage from the 1990s to the 2000s, with a sharp change in maize output in 2002. This is likely due to systematic measurement error that was corrected with the 2002 agricultural census.[4]

In Table 2 we report annual maize net import (imports – exports) statistics for the four study countries over the period 2000-2010. All four countries are engaged in the international maize trade, although volumes of both exports and imports are low relative to consumption. Only in Kenya does international trade account for a significant portion of traded maize, with substantial variation between years. In Figure 3, which shows maize production and imports in Kenya for the period 1997-2010, it is only in 1997 and 2009 that net maize imports account for more than 20% of consumption.

Since the 1990s, in lockstep with the general shift in the developing world away from planning and toward market determination of prices and trade flows, governments in the four study countries have largely withdrawn from direct participation in the production, distribution, or pricing of food and fuel. The exception is the price of fuel in Ethiopia, which is set for each major market by the Ministry of Trade and Industry. Other relevant policies, such as tariffs, procurement auctions, maintenance of strategic grain reserves, and occassional *ad hoc* export bans, are discussed in Appendix A.

Data sources and descriptive statistics

Figure 4 shows the location of the 17 markets for which we could match fuel and maize price series. All are urban areas, but of varying size and remoteness from global markets. The POE markets – Mombasa, Kenya; Dar es Salaam, Tanzania; Kampala, Uganda; and Addis Ababa, Ethiopia – are indicated with a

[3] See FAOstat for details by crop. Rashid (2010) gives a detailed descriptive analysis for Ethiopia.
[4] While the FAO data are the best available, we suggest that the output and acreage numbers be read with caution. Recent work on data quality in African agriculture statistics shows significant measurement error (Jerven 2013).

larger font size. We use monthly average prices for all data series because higher frequency data were not available for sub-national petrol and maize markets. We focus on the period 2000-2012, with slight variation in the coverage period due to data limitations.

Global market price series are from the World Bank Global Economic Monitor (GEM) commodity price database. Crude oil prices are expressed in nominal USD per barrel, and are the equally weighted average of Brent, Dubai, and West Texas Intermediate spot prices. Maize prices are nominal USD per metric ton for number 2 yellow maize, f.o.b. at US Gulf ports. In Figure 5 we plot the global price series over the study period. The series co-move somewhat, although no obvious causal relationship presents itself. The correlation coefficient between the nominal price series is 0.83. After deflating to 2005 prices using the world CPI measure from the IMF IFS data, the correlation coefficient is 0.45.

In regressions with both global and national prices, we use the monthly CPI and $US exchange rate for each study country. These data are from the IMF International Financial Statistics database.

Wholesale prices of white maize for markets in Kenya are from the USAID-funded Famine Early Warning System (FEWS). Average wholesale maize prices for Tanzania were provided by the Ministry of Agriculture, via the International Growth Center (IGC) office in Dar es Salaam. Wholesale maize prices for Ethiopia markets are from the website of the Ethiopia Grain Trade Enterprise (EGTE). Retail white maize prices for Uganda markets are from the Regional Agricultural Trade Intelligence Network (RATIN) of the East Africa Grain Council (wholesale prices were not available).[5]

In Figures 6-9 we plot the POE maize prices for each country against global maize prices.[6] In each figure, global prices in month *t* are converted to local, nominal currency units using the exchange rate in month *t*. While intra-annual seasonality related to the harvest cycle is clearly visible in each graph, the long-run trajectory of prices in each market tracks the shifts in global prices.

Table 3 shows the average price of maize at study markets, along with the number and percentage of study months in which the price in each market was the lowest in the country. Not surprisingly, the lowest average prices are in the trading centers near the maize breadbasket regions (Bahir Dar, Ethiopia; Eldoret/Nakuru, Kenya; Mbeya, Tanzania; Gulu, Uganda). Perhaps the only surprise in Table 3 is that maize prices in Mombasa, Kenya, tend to be lower than those in Kisumu and Nairobi. Very little maize is grown in the coastal areas around Mombasa. This likely reflects the fact that the coastal region is primarily served by imports rather than by trade of domestically produced maize, so that the net maize

[5] Price series for Uganda are less complete than those for other markets, with very few observations after 2008 and spells of missing data in other years. However, there are alternative sources of prices for Uganda that overlap the RATIN price series in some periods, such as FEWS, Uganda FoodNet, and the FAO. To accommodate missing values in the Uganda RATIN series, we predict prices using least squares estimates based on regressions of RATIN prices on these other price series, and on RATIN prices in non-study markets. Details available upon request.
[6] Note that farmers in study countries typically grow white maize, but we have global prices for yellow maize. We believe this to be of little consequence: data is only maintained for one type of maize because the two are broadly considered substitutes.

transport costs to Mombasa are lower for international exporters than those to more centrally located cities.

For fuel prices we use petrol prices at the pump rather than the arguably more relevant diesel prices, because of data availability.[7] The market-specific mandated prices in Ethiopia, along with the exact dates of all price changes, were provided by the Ministry of Trade and Industry. Petrol prices in Uganda are monthly averages provided by the Consumer Price Index division of the Bureau of Statistics. Monthly average retail prices for markets in Kenya were provided by the Kenya National Bureau of Statistics. [8] Monthly average retail petrol prices for markets in Tanzania were provided by the Bank of Tanzania and IGC.

Figures 10-13 show the time path of POE fuel prices along with global oil prices. It is clear that each POE-global pair closely co-move, with changes in the POE price tending to lag global price changes. Infrequent updating of the Addis Ababa petrol price, a consequence of government-mandated pricing, is clear in Figure 10.

Table 4 shows the average price of fuel at sub-national markets in the sample data, along with the number and percentage of study months in which the price in each market was the lowest in the country. As expected for an imported good, fuel prices in the POE market are the lowest on average in Ethiopia, Kenya, and Tanzania. In Uganda, retail fuel prices in the Kampala are slightly higher on average than in Mbale, indicating that some fuel imports from Kenya may be diverted directly to Mbale (which is near the border) without first passing through Kampala.

3. Empirical Approach

All of the price series in this paper are I(1).[9] Our empirical strategy involves stepwise estimation of error correction models treating the larger market price (global price in one step, POE price in the next) as weakly exogenous to the smaller market price. Figure 14 summarizes the approach. We begin by estimating the relationship between the global prices of oil and maize (step 1). We then estimate the impact of changes in global market prices of each commodity on the POE prices in each country, separately, treating the global price as weakly exogenous (step 2). Changes in global oil prices are included in the POE maize equations in order to allow for variable transport cost margins at the border. We then estimate the link between POE petrol prices and petrol prices in geographically dispersed sub-

[7] This is of minimal concern, as the prices are highly correlated in those markets for which we have both.
[8] In one location we have to merge series from proximate towns. We could assemble fuel price data from Nakuru but not from Eldoret, while the maize price series from Eldoret was complete and that from Nakuru truncated. Since these are quite proximate and the two main urban concentrations of Rift Valley Province in Kenya, we merge them into a synthetic series, using Eldoret's maize prices and Nakuru's fuel prices.
[9] Results, based on the modified Dickey-Fuller test (Elliott et al. 1996) and the Phillips and Perron (1988) test, are available upon request.

national markets (step 3). Finally, we estimate the pass-through rates of maize prices from the POE markets to other sub-national maize markets, allowing changes in local fuel prices to impact the maize price spread (step 4).[10]

This approach rests on four key identifying assumptions:

Assumption 1. *Each country is a price taker on global markets for both maize and oil, so that the global market price is at least weakly exogenous to POE prices.* This is an innocuous assumption given each country's small share of global trade in these two commodities.

Assumption 2. *There is no feedback from maize prices to fuel prices within study countries, rendering petrol prices weakly exogenous to maize prices intra-nationally.* This is also a mild assumption given the absence of any significant biofuel production and the small share of maize in gross freight haulage within the region.

Assumption 3. *Global prices are transmitted to local markets via the POE, so that the POE prices are weakly exogenous to interior market prices*. This assumption follows from assumption 1 and the continuity of international trade in both commodities in almost all months. As a consequence, any disequilibrium between prices at the POE and those in other market *j* is resolved through adjustment in *j*. While this may be a simplification in the very short run, it is surely a benign assumption in the medium and long term, because trade with international markets, and therefore the price-setting mechanism, is mediated primarily through the POE.

Assumption 4. *The exchange rate is weakly exogenous to changes in oil and maize prices over the study period.* If there is an identification challenge in the paper, it relates to this fourth assumption. A full model of exchange rate determination would involve numerous other variables, and would take us well beyond the scope of this paper. However, we include monthly exchange rates in the long run equations of all models linking global prices to domestic prices, and in Appendix B we show that in general, exchange rates do not respond to maize or oil market disequilibrium. Nevertheless, over a long enough time horizon, exchange rates are likely endogenous to commodity price changes. In the interpretation of results, we accommodate this possibility by separately assuming zero and complete exchange rate adjustment to changes in commodity prices, which gives bounds on cumulative pass-through elasticities.

[10] Enders (2010) lays out the general approach to VAR and error correction models that we use in this paper.

Finally, in regard to the multi-step estimation procedure, we believe it is important to estimate the POE-global price link in a first stage because this allows us to measure the effects of country-specific tariffs and import policies. Then, equations linking the POE price to each sub-national market allow for distance, infrastructural differences, and possible local market effects to differentially affect the rate at which global prices transmit within national markets.[11,12]

Step 1. Global Oil - Global Maize Price Linkages

Rank tests for the maximum number of cointegrating vectors (Johansen 1991, 1995) indicate that the global price series are not cointegrated at conventional levels of significance (Appendix D has results of all cointegration tests). This result does not change if we include a trend or suppress the constant in the cointegrating equation. Using different, US price series, Zhang et al. (2009) and Serra et al. (2011) similarly find no evidence of cointegration between monthly crude oil and corn price series. Zhang et al. (2010) find precisely the same result using the same data series, but with somewhat earlier dates.

This finding does not account for the ethanol mandate that took effect in October 2006, under the United States Energy Policy Act of 2005, which may have fundamentally changed the relationship between fossil fuel prices and maize prices (de Gorter et al. 2013). However, Johansen tests on data from October 2006 onwards still do not show evidence of cointegration between the series. This result is consistent across specifications (including trends, suppressing constants), and holds for both nominal and real prices (not shown). The lack of cointegration between these series is perhaps evident in Figure 15, which shows nominal oil and maize prices from October 2006 – November 2012. While the prices appear to follow similar trends, it is not apparent that one series regularly leads the other, nor that they maintain some fixed additive or proportional relationship.

Therefore, in order to formally model the observed co-movement between global oil prices and global maize prices without imposing an unsubstantiated long-run stationary relationship, we estimate a reduced form vector autoregression (VAR), in first differences, separately for the entire sample and for the period from October 2006 onwards. A lag length of 1 month is used in both specifications, based on the Schwarz-Bayesian information criterion.

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[11] For multiple reasons, we do not try to control for policy changes with dummies for possible structural breaks. First, the time series are relatively short, and many policy changes (e.g., fuel price caps) were concentrated near the very start or end of the study period. Second, there are few clear, discrete policy changes that can be confidently assigned to specific months, as many policy instruments (e.g., export bans) have been episodically implemented and not formally recorded in any sources we can find. Third, many relevant policies are endogenous to market conditions; for example, export bans have been introduced explicitly in response to higher market prices.

[12] We also could estimate this as a vector error correction mechanism, stacking all of the various market prices. But interpretation of the resulting multiple cointegrating equations is considerably less straightforward than is interpretation of the cointegration of two price series. We therefore strongly favor estimating bilateral price relationships, even with the resulting inefficiency in parameter estimates.

Step 2. Global-POE Price Linkages

For all four countries, Johansen tests indicate the presence of a single cointegrating vector between global oil prices, POE fuel prices, and the exchange rate, with a constant in the long-run equation (Appendix D). Therefore, for each country we test a variety of fuel price specifications (varying the lag length *K* and the inclusion of a trend in each equation) based on the following two-stage asymmetric error-correction model (ECM): [13]

(1) $$F_t^{POE} = \alpha + \beta_1 F_t^G + \beta_2 ER_t + \varepsilon_t$$

(2) $$\Delta F_t^{POE} = \delta_0 ECT_t^{neg} + \delta_1 ECT_t^{pos} + \delta_2 \Delta CPI_t + \sum_{k=1}^{K} \{\delta_{4k-1} \Delta F_{t-k}^{POE} + \delta_{4k} \Delta F_{t-1}^{G} + \delta_{4k+1} \Delta ER_{t-k} + \delta_{4k+2} \Delta CPI_{t-k}\} + \nu_t$$

where F_t^{POE} is the POE fuel price in month *t*, and F_t^G is the global oil price, ER_t is the US dollar exchange rate (local currency over USD), CPI_t is the consumer price index in the study country, and ε_t and ν_t are statistical error terms. Under co-integration, two-step estimation of equations 1 and 2 by OLS generates super-consistent estimates of the $\hat{\beta}$ estimates of interest (Engle and Granger 1987).

Equation 1 represents the cointegrating vector, i.e., the long run equilibrium relationship between the variables. In general, the average elasticity of price p_j to price p_i, designated η_{ji}, is calculated as $\hat{\eta}_{ji} = \frac{\hat{\beta}_i \bar{p}_i}{\bar{p}_j}$, where $\bar{p}_k$ is the average of price *k* over the observations used in the regression, for $k \epsilon \{i, j\}$, and $\hat{\beta}_i$ is the estimated coefficient on price *i* in the relevant regression. For each study country we can estimate the long-run elasticity of the POE fuel price with respect to the global oil price (exchange rate) by setting $p_j = F^{POE}$ and $p_i = F^G$ ($p_i = ER$), and using the estimated coefficient from equation 1.

Equation 2 captures the short-run dynamics. We include the change in the monthly inflation rate, ΔCPI_t, to control for the changing value of the domestic currency. The error correction term $ECT_t = F_{t-1}^{POE} - \hat{\alpha} - \hat{\beta}_1 F_{t-1}^G - \hat{\beta}_2 ER_{t-1}$, is the residual from equation 1, which measures period *t-1* deviations from the long run stationary relationship. The *neg* and *pos* superscripts indicate the sign of the residuals (i.e., the variable $ECT_t^{neg} = ECT_t$ if $ECT_t < 0$, equals 0 otherwise, and complementarily for ECT_t^{pos}). The δ_0 and δ_1 parameters can be interpreted as the speed-of-adjustment parameters for negative and positive deviations from the long-run equilibrium, respectively. We expect those parameter estimates to be negative. The absolute values of these estimates, $|\hat{\delta}_0|$ and $|\hat{\delta}_1|$, give the share of the deviation from long-run equilibrium that decays each month.

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[13] We do not allow for thresholds in the error correction mechanism, largely out of concern for overfitting, given our allowance for asymmetric adjustment.

There are various reasons to expect asymmetries in adjustment to long-run equilibrium. The relationship in equations 1 and 2 reflects both spatial price transmission and transformation of crude oil inputs into refined fuel, and substitution possibilities among alternative fuels can naturally lead to asymmetries in the vertical price transmission (Borenstein et al. 1997). Asymmetric adjustment may also arise due to firm-level market power, fragmented wholesale distribution systems (Peltzman 2000), government policy interventions, or infrastructural bottlenecks such as limited port capacity (Meyer and von Cramon-Taubadel 2004). These various effects cannot be separately identified in our data. But because our interest is in estimating the pass-through effects of long-run price *increases*, the asymmetric structure is important for ensuring that we identify the average response to negative *ECT* terms (i.e., months in which the POE price is low relative to its stationary relationship with the global price).

We estimate a similar series of ECM models for maize. The primary modification is that we include the global oil price in the maize ECM system, to allow for changes in fuel costs to impact the relationship between POE maize prices and global maize prices:

(3) $$M_t^{POE} = \alpha + \beta_1 M_t^G + \beta_2 F_t^G + \beta_3 ER_t + \varepsilon_t$$

(4) $$\Delta M_t^{POE} = \delta_0 ECT_t^{neg} + \delta_1 ECT_t^{pos} + \delta_2 \Delta CPI_t + \sum_{k=1}^{K} \{\delta_{5k-2} \Delta M_{t-k}^{POE} + \delta_{5k-1} \Delta M_{t-1}^G + \delta_{5k} \Delta F_{t-1}^G + \delta_{5k+1} \Delta ER_{t-k} + \delta_{5k+2} \Delta CPI_{t-k}\} + \nu_t$$

where M_t^{POE} is the POE maize price in month *t*, M_t^G is the global maize price in month *t*, and other variables are as before.

The relationship between domestic maize prices and global maize prices is complicated by the fact that all of the study countries are major maize producers. While domestic prices in these four countries are necessarily linked to global price movements through near-constant cross-border trade, policymakers have supply-side tools to stabilize maize prices that are not available for fuel prices (e.g., export bans, or input subsidy programs). Indeed, a thread of the literature exploring the impacts of the 2008-2011 global food price shocks on local food economies emphasizes the extent to which national governments were able to use a range of policy instruments to buffer their constituents against price movements.[14] Nonetheless, global maize prices are necessarily transmitted to domestic maize prices in these small economies through ports-of-entry. In almost all periods the return to transporting maize from the breadbasket region(s) to any other market is always constrained by the available return from transporting the crop to the port for export.

Step 3. Fuel price transmission from POE to other sub-national markets

[14] Baltzer (2013) offers a useful summary of that literature.

We expect fuel prices in sub-national markets other than the POE to reflect POE prices plus domestic transport costs. Deviations from this relationship – due to supply chain disruptions, localized fuel demand shocks related to seasonality, or other forces – should not persist for long under reasonably competitive conditions. Not surprisingly, Johansen tests clearly indicate the presence of a single cointegrating vector between the POE market price of fuel and the fuel price in each non-POE market in the sample. In all cases the Schwarz Bayesian criterion indicates an optimal lag length of two months in levels (therefore 1 month in differences). Accordingly, for each POE/other market pair, we estimate the following ECM:

(5) $$F_t^j = \alpha + \beta F_t^{POE} + \varepsilon_t$$

(6) $$\Delta F_t^j = \delta_0 ECT_t^{neg} + \delta_1 ECT_t^{pos} + \delta_2 \Delta F_{t-1}^{POE} + \delta_3 \Delta F_{t-1}^j + \omega_t$$

where F_t^j is the fuel price in "other market" *j*, in month *t*, and all other terms are as described above. For the within-country specifications we work entirely in nominal, local currency terms.

Step 4. Maize price transmission from POE to other sub-national markets

The final relationships of interest are those between POE maize prices and maize prices at sub-national markets. Because crop transport in this region is conducted primarily via lorry, we allow fuel prices to affect maize price spreads between the POE and other markets. As in the above sections, rank tests show that in all specifications there is at most a single cointegrating vector between POE maize prices, other market maize prices, and other market fuel prices, with an optimal lag of length of two months (in levels).

The error-correction framework takes the following form:

(7) $$M_t^j = \alpha + \beta_1 M_t^{POE} + \beta_2 F_t^j + \varepsilon_t$$

(8) $$\Delta M_t^j = \delta_0 ECT_t^{neg} + \delta_1 ECT_t^{pos} + \delta_2 \Delta M_{t-1}^{POE} + \delta_3 \Delta F_{t-1}^j + \delta_4 \Delta M_{t-1}^j + \omega_t$$

where M_t^j is the price of maize in market j and all other variables are as before. The hypothesis $H_0 : \beta_2 > 0$ captures the expected effect of fuel prices on long-run maize price spreads.

We estimate all of the equations in Steps 2-4 using ordinary least squares. In some cases, after initial estimation, we added lags to the second-stage equations to ensure white noise residuals (Enders 2010).

4. Results

Global Price Linkages

Table 5 shows the results of the reduced form VAR linking changes in oil and maize prices on global markets. We show separate results for the periods January 2000 – October 2012 and October 2006 – October 2012, in case the change in US ethanol policy affects the underlying inter-commodity price relationship. We can reject the null of a unit root in the residuals for all equations (not shown). Coefficient estimates are generally similar over the two periods. In neither period do maize prices exhibit a statistically or economically significant response to lagged changes in oil prices. Maize prices are weakly auto-correlated. Oil prices, however, demonstrate substantial auto-correlation, and positive changes in maize prices tend to drive up oil prices. This is consistent with previous findings by Serra et al. (2011) that corn price shocks cause increases in ethanol prices, which in turn induce adjustments in gasoline prices, which feed back to crude oil markets.

While the estimates in Table 5 cannot be interpreted as causal, they do suggest that we can reject a model in which global oil price movements directly affect maize price movements on the main international market. This calls into question popular claims that global oil prices shocks trigger global maize market adjustments. Of course, oil prices and maize prices may still co-move, either because of correlated global commodity price shocks due to common underlying factors, as other recent studies have found (Gilbert 2010, Enders and Holt 2012, Byrne et al. 2013), or because the relationship is nonlinear and involves other variables, rendering it too nuanced for easy detection with our data and approach (de Gorter et al. 2013). However, if global oil prices do have a positive but undetected effect on global maize prices, that will only amplify the effects reported below.

Global-POE price transmission

Table 6 shows the estimates of equation 1, for all four countries. The final row of the table shows the mean POE price over the study period, in local currency units. POE retail fuel prices are increasing in both global oil prices and the exchange rate, as expected. Standard hypothesis testing on these coefficients is not possible because the error term is nonstationary, therefore we do not provide stars indicating statistical significance.

The key findings in Table 6 are summarized in the average pass-through elasticities for oil price changes and exchange rate changes, which are listed in the lower half of the table. Estimates of POE petrol price elasticities with respect to the global oil price are remarkably similar across countries. On average, a 1% increase in the price of oil on world markets leads to an increase in the POE petrol price of 0.38-0.46%. Petrol price elasticities with respect to the exchange rate are higher and more variable, ranging from 0.85 in Kenya to 1.52 in Ethiopia. Over the study period, slightly less than half of the increase in nominal fuel prices in the POE markets is due to changes in nominal prices of global oil. The remainder of the increase is driven by exchange rate depreciation.

Table 7 shows the estimates of equation 2. All coefficient estimates have the expected sign, when significant. Adjustment back to the long run equilibrium is not instantaneous, but is still reasonably fast on average, with monthly adjustment rates ranging from 14-56%. Increases in global oil prices generally transmit faster than do price decreases. However, F-tests for asymmetric adjustment indicate that only in Tanzania is the difference statistically significant. This is consistent with various import bottlenecks, such as port constraints, foreign exchange constraints, or contracting lags, and also with imperfect competition in which importers adjust prices upward more quickly than downward.

Estimates of equation 3, the cointegrating vectors linking global maize prices to POE maize prices, are reported in Table 8. POE maize–global maize pass-through elasticities (lower half of table) exhibit greater heterogeneity than did the analogous POE petrol–global oil elasticities, ranging from 0.22 in Kenya to 0.82 in Ethiopia. These results correspond with an ordering of the degree to which central governments intervene in maize markets, as Kenya's more activist tariff and parastatal marketing board policies translate into weaker transmission of global maize prices to the national market than in neighboring countries. Pass-through elasticities of POE maize with respect to global oil prices are also substantial, lying in the range 0.08-0.36, even after accounting for the direct impact of maize price changes. In Kenya, by far the biggest maize importer in the region, a 1% increase in global oil prices exhibits greater upward pressure on Mombasa POE maize prices (specifically, 0.31% increase) than does a 1% increase in global maize prices (0.22%), underscoring the importance of transport costs to the pricing of bulk grains. As with fuel prices, exchange rate elasticities vary widely, and are responsible for any remaining changes in nominal POE maize prices after accounting for the direct impact of global maize and global oil price changes.

In Figure 16 we plot the monthly average residuals from estimates of equation 3, normalized by the overall mean POE maize price in each respective country. Seasonal patterns apparent in the deviations from long-run equilibrium. These are consistent with intra-annual fluctuations in domestic supply, due to the agricultural production cycle. For example, maize harvests in Ethiopia are concentrated in the months September-November, which coincides with a drop in the Addis Ababa maize price vis-à-vis its long-run relationship to the world price.

Second stage ECM results for the global-to-POE maize price relationship, based on equation 4, are shown in Table 9. The error correction terms are highly significant in the wake of a positive deviation from long-run equilibrium price (ECT^{pos}), exhibiting the opposite pattern from the asymmetric models of POE fuel prices. One interpretation of the asymmetric adjustment is that price arbitrage via exports is logistically difficult due to port queues, regulatory barriers, the absence of short-term forward contracting, and storage bottlenecks. On the other side, rapid recovery from higher prices may reflect the roles of food aid, explicit export bans, and strategic release of grain reserves in mitigating the pace of food price increases in the POE markets. Higher-than-equilibrium POE maize prices are generally absorbed in no more than 6-8 months, with the arrival of the next harvest. Lower-than-equilibrium prices (ECT^{neg}) persist far longer. However, only in Ethiopia is the asymmetry statistically significant at the 5% level. Coefficient estimates on lagged differences in global oil prices are not significant in any of the equations, suggesting that changes in transport costs matter more for the long-run equilibrium (Table 8) than for short-run price dynamics.

Within-country petrol price transmission

Table 10 shows the estimated co-integrating vectors based on equation 5, which link fuel prices in sub-national markets to the POE fuel price. Most of the estimated models fit the data very closely. Fuel markets are very well integrated within the study countries. The β coefficient estimates from equation 3 are all very close to unity, as are the estimated pass-through elasticities. This is clear empirical support for the law of one price in fuel markets, which is expected given that ports-of-entry are the sole domestic sources of liquid transport fuels in each country.

Second-stage ECM estimates, based on equation 6, are provided in Table 11. In all markets, POE price increases transmit faster than POE price decreases. However, at 5% significance we can reject the null of symmetric adjustment for only 2 of 13 markets. Faster pass-through of price increases could be consistent with the existence of structural impediments to moving additional fuel quickly to non-POE markets, or with imperfect competition among fuel distributors. Overall, equilibrium is restored very rapidly when POE prices increase. Adjustment rates range from 31-74% in Ethiopia, Tanzania, and Uganda. In Kenya, adjustment speeds are somewhat slower on average, though still rapid.

Within-country maize price transmission

Table 12 shows the estimates of equation 7 for each of the sub-national markets. For 9 of 13 markets – those in Ethiopia and Kenya, as well as Arusha, Dodoma, and Mbale – both the point estimates of β_1 and the POE maize price pass-through elasticities are close to unity, indicating conformity with the law of one price. Within-country maize price elasticities are lower, in the 0.48-0.80 range, for the other four markets in Tanzania and Uganda: Kigoma, Mbeya, Gulu, and Mbarara. These are the markets farthest from the POE markets (Figure 4). These latter four markets also exhibit the largest positive pass-through elasticities with respect to local fuel prices, ranging from 0.29 in Mbeya to 0.76 in Mbarara. In Mbarara the estimated petrol price elasticity is higher than the POE maize price elasticity, and in Gulu and Kigoma the estimated petrol price elasticity is approximately two thirds that of the maize price elasticity estimate.

In contrast, petrol price elasticities at Ethiopian markets, Arusha, Dodoma, and Eldoret/Nakuru are all less than 0.06 in absolute magnitude. The outlier in Table 12 is the -0.62 petrol price elasticity in

Mbale. Because these coefficients must be interpreted with reference to the long run relationship between the POE price and the sub-national market price, this suggests that increases in transport costs tend to drive down the price of maize in Mbale relative to the price in Kampala. Because of its location near the Kenya border, it is possible that Mbale receives some imports directly, bypassing Kampala entirely.

These results underscore the crucial role of transport to more remote markets, both in attenuating food price pass-through and in augmenting the impact of global oil prices on transport costs. The innermost markets in our study (Gulu, Mbarara, Kigoma, and arguably Mbeya) give some indication of the likely impacts of oil price changes on food prices in land-locked nations and remote trading towns. In these markets, transport costs are as or nearly as important as POE maize prices in determining maize prices. Figure 16 depicts the clear positive relationship between the estimated elasticities of local maize prices with respect to global oil prices as a function of distance from POE. Conversely, in Figure 17 we plot the estimated elasticities of local maize prices with respect to global maize prices as a function of distance from the market nearest the domestic maize surplus zone (the "breadbasket"). The clear positive relationships between distance and estimated pass-through rates, in both figures, highlight the importance of transport costs in local maize price determination.

In Table 13 we report the second-stage results of the asymmetric ECM based on equation 8. Once again, all of the ECT coefficients have the expected, negative sign (apart from the coefficient on $L.ECT_t^{pos}$ in the Mbale equation, which is not statistically significant). Adjustment back to equilibrium is reasonably fast, with rates ranging from 19-92% per month, consistent with prior findings for Tanzania maize markets (van Campenhout 2007). Many of the maize price series demonstrate positive autocorrelation, and likewise respond positively in the short-run to lagged changes in the POE maize price. Asymmetries in adjustment are only statistically significant in Dire Dawa and Mbale. Just as with the global-POE adjustment processes, fuel prices have little effect on the short run dynamics; only 2 of 13 markets have a statistically significant, positive point estimate on lagged fuel price in the maize ECM regressions. In the breadbasket markets of Bahir Dar, Gulu and Mbeya, the (albeit statistically insignificant) short term impact of a fuel price increase is to *decrease* local maize prices, likely because of temporary reductions in the profitability of transporting maize away from these markets. Overall, however, fuel prices play a larger role in determining the long run spatial equilibrium price relationships (Table 12) than in mediating adjustments to those equilibria (Table 13).

5. Discussion

The estimated pass-through elasticities from the preceding section tell us about relationships between price pairs. But if we want to estimate the full impact of a global oil price increase on sub-national maize market equilibrium prices in east Africa, we need to integrate our estimates of the co-integrating vectors that describe the long-run stationary relationships among various price series. Because we find no statistically significant impact of global oil prices on global maize prices, consistent with much of the prior literature, we assume away any transmission through that pathway (although we will consider scenarios in which maize and oil prices co-move). Note that any positive effect of global oil prices on global maize prices, due perhaps to diversion of grain supply from food and feed markets to fuel markets, would only reinforce our core findings that global oil markets significantly maize prices in east Africa.

We report above that fuel price shocks transmit much more rapidly within the four study countries than do maize price shocks. Table 14 summarizes the speed-of-adjustment findings by showing the number of months needed to absorb 80% of a price increase. In all four countries, it takes substantially longer to return to POE maize price equilibrium after a global maize price rise than it does to return to POE petrol price equilibrium following a global oil price rise (compare columns 1 and 3). Likewise, in Tanzania and Uganda, where governments intervene less in fuel markets than in Ethiopia or Kenya, POE petrol price changes transmit more rapidly within the country than do POE maize price changes (compare columns 2 and 4).

The implication of this pattern is that in the face of correlated increases in global maize and oil prices, increases in transport costs drive up sub-national maize prices across east Africa more quickly than do the direct pass-through effects of higher grain prices on global markets. This is most clear from a comparison of the two rightmost columns in Table 14, which show the sums of columns 3 and 4, and of columns 1, 2, and 4, respectively.[15] In all cases, sub-national maize market prices converge to their new long-run equilibrium substantially faster in response to a global oil price shock than to a global maize price shock. In 11 of 17 markets, the number of months needed to absorb an oil price rise is less than half of that needed to absorb a global maize price rise. While it is not surprising that adjustment speeds are slower for a good that is produced domestically and sometimes subject to government intervention on food security grounds (such as *ad hoc* export bans), the magnitude of the difference is striking.

Of course, rapid pass-through of fuel price increases matters only insomuch as the impact of global oil price increases on local maize prices is of significant magnitude. It is. Table 15 reports the estimated cumulative pass-through elasticities of local maize prices with respect to increases in global maize prices, global oil prices, and exchange rates, based on the findings in Tables 6, 8, 10 and 12.[16]

Local maize price elasticities with respect to global maize prices (column 1) are highest in Ethiopia (0.74-0.82), and lower but still substantial in the other three countries, ranging between 0.20-0.25 in Kenya, 0.22-0.36 in Tanzania, and 0.23-0.53 in Uganda. In Table 12 we saw that within each country, long-run spatial equilibrium in maize prices routinely corresponded with the predictions of the

[15] Note that these are upper bounds on the speed of convergence to long-run equilibria. By directly adding the previous columns we implicitly assume that adjustment occurs sequentially rather than simultaneously.
[16] Entries in Table 15 are the products of the elasticities from the relevant links in the supply chain (see Figure 14).

law of one price, consistent with a longstanding literature (Engel and Rogers 1996, Evans 2003, Anderson and van Wincoop 2004). It is the impact of trade across international frontiers (Table 8) which dampens maize-to-maize price transmission in Table 15.

In column 3 we see that exchange rate elasticities vary considerably across countries, from very low estimates in Ethiopia (0.11-0.23) to substantially greater figures in Kenya (2.07-2.46). At the country level these estimates are ordered inversely from the global maize price elasticities in column 1, hinting at the role of macroeconomic adjustment to external terms of trade shocks in determining local equilibrium prices. In fact, these cross-country differences likely reflect differences in the importance of maize in the general price indices (which then impacts the equilibrium exchange rate). Maize is most critical to consumption in Kenya, and that is where we see exchange rate adjustment having a substantially larger effect on equilibrium maize prices than it does in the other countries.

The findings in Table 15 that are most central to this paper are the cumulative impacts of global oil price changes on local maize prices, in column 2. In all of the markets in Kenya, as well as in the more remote markets of Gulu and Mbarara, in Uganda, and Kigoma, Tanzania, cumulative pass-through maize price elasticities from global oil price increases are greater than those from global maize price increases. In Mbeya, Tanzania, one of the other remote trading centers in the study (though still a major maize producing region), the estimated global oil price elasticity of 0.19 is two thirds of the estimated global maize price elasticity (0.28). For markets in Ethiopia, as well as Kampala, Arusha, and Dar es Salaam (the largest cities in Uganda and Tanzania), cumulative elasticities with respect to global oil prices are a little less than half the magnitude of those with respect to global maize prices. Across the sample, the average global maize price elasticity is 0.42, while the average global oil price elasticity is 0.26.[17] Recall that these global oil price elasticities assume no link between oil and maize prices on global markets; any such link would indicate that the true average elasticity of local maize prices to global oil prices is greater than 0.26. This underscores the often-underappreciated importance of *variable* transport costs in determining equilibrium food prices in infrastructure-deficient Africa.

Kenya is the only study country in which estimates of local maize price elasticities with respect to global oil prices are systematically greater than those with respect to global maize prices. Kenya is also the only study country in which farmers applied substantial amounts of inorganic fertilizers during the study period. Because much inorganic fertilizer production relies on natural gas feedstock, the price of which is closely linked to the price of oil on global markets, this raises the possibility that the link

[17] These estimated pass-through rates significantly exceed IMF (2009) findings that only 3-21% of global food price shocks transmit to food prices within Kenya, Tanzania or Uganda, and that the pass through rate of world oil prices to domestic food prices is only 11% in Uganda and statistically insignificantly different from zero for Kenya and Tanzania. However, the IMF findings are based on simpler vector autoregression methods that do not account for the nonstationarity of the series, and use aggregate national price series rather than market-specific prices.

between global oil prices and Kenya maize prices may be partly mediated through an increase in domestic maize production costs, rather than transport costs. Such an impact would not be expected to persist indefinitely because in the long run Kenya maize prices are tied to global maize prices, which should be invariant to production costs in Kenya, a very small producer in global terms. Nonetheless, in a robustness check we explore this potential channel because of the notable qualitative difference between the results for Kenya and those for the other study countries, as well as the fact that Kenya is the only study country where fertilizer use on maize is widespread. Were we to find that fertilizer costs have a substantial impact on Kenya maize prices, a potential (though unlikely) alternative to the transport costs interpretation of our core results is that maize markets near Mombasa are served primarily by imports, while maize markets in the western population centers of Kenya are served by local production that relies on inorganic fertilizer.

However, using a limited (though best available) monthly time series of Kenya fertilizer prices, which includes monthly average di-ammonium phosphate (DAP) prices in Nairobi for the period 2007-2011, we find no impact of domestic fertilizer prices on equilibrium maize prices in Kenya (see Appendix C for details). At the global level there is a clear link between oil prices and fertilizer prices,[18] but this does not influence maize prices in east Africa independently of whatever effects are mediated through the price of maize on global markets.

Finally, Table 16 shows the full impact on local maize prices from four price change scenarios. Scenarios 1 and 2 directly correspond to the price changes that implicitly underlie the elasticities presented in Table 15: a 1% increase in the global oil price and a 1% increase in the global maize price, respectively. The third scenario considers a generalized increase in global commodity prices that generates correlated 1% price rises for both crude oil and maize (following Gilbert 2010, Enders and Holt 2012 or Byrne et al. 2013). Lastly, the fourth scenario incorporates possible macroeconomic impacts on exchange rates due to changes in the prices of tradables, by assuming that global oil prices, global maize prices, and exchange rates all increase 1% over their baseline values. Scenarios 3 and 4, therefore, provide bounds on the total effect allowing for zero and complete exchange rate adjustment, respectively. Because correlated commodity price movements are commonplace (Gilbert 2010, Enders and Holt 2012, Byrne et al. 2013, Baffes and Dennis 2013), we consider scenarios 3 and 4 to be the most realistic.

We use an additive linear framework to model long-run relationships, therefore estimates under scenario 3 are the sum of those under scenarios 1 and 2. Aggregate pass-through rates in response to perfectly correlated global maize and oil price shocks are high: over 100% pass-through in Ethiopia, 52-63% in Kenya, 43-47% in Tanzania, and 56-70% in Uganda. These estimated changes occur in the absence of any changes in the exchange rate.

[18] Results available upon request.

When the exchange rate depreciates by 1% as well, in scenario 4, the cumulative local maize price elasticities are all greater than unity. In most Ugandan markets the estimated elasticity approaches 2, and estimates are in the 2.61-3.06 range across Kenyan markets. These are upper bounds on true pass-through elasticities, since they are premised on an out-of-equilibrium simulation of an exchange rate change.[19] However, the interesting finding in scenario 4 is the disparity in the relative importance of exchange rate changes across the study countries. In Ethiopia, real domestic prices are closely matched to real global prices, so that exchange rate adjustment has only a minor effect on pass-through rates. Exchange rate effects in Kenya, on the other hand, are especially pronounced (as noted earlier).

The broad implication of our findings is that *both* global oil and global maize prices exert considerable influence on sub-national maize prices across east Africa. Although cross-border price transmission is less complete than that within countries – which largely follows the law of one price in long-run equilibrium for both fuel and maize – the most narrow estimates, assuming global oil price shocks are uncorrelated with global maize prices and exchange rates, still suggest a pass-through ratio of 0.26, while more realistic estimates that allow for such correlation quickly approach or exceed 1. Equally importantly, global oil prices seem to impact sub-national maize prices through transport cost effects, not by inducing changes in global maize prices nor by driving up local costs of farm-level production, although these latter two are the pathways most frequently discussed in the literature and the popular press. These estimated magnitudes and the fact that local maize price adjustment to global oil market shocks occurs much faster than it does to global maize market shocks both suggest that researchers and policymakers concerned about the food price effects of oil market shocks ought to pay more attention to transport systems and their variable costs.

6. Conclusions

The potential of global crude oil price shocks to disrupt food markets in developing countries naturally concerns astute observers, given experiences over the past half dozen years. In this paper we explore those linkages systematically. We first look at inter-commodity oil-maize price transmission in global markets. Then we estimate spatiotemporal price transmission from global crude oil markets to national and sub-national petrol fuel markets in east Africa, and then repeat the exercise for maize markets, allowing oil prices to influence maize prices independently as a way to capture the prospective effects of variable transport costs. To the best of our knowledge, this is the first study to explore both inter-commodity and intra-national price transmission from oil to cereals markets. Moreover, it brings out how the mechanisms that might lead global oil prices to influence maize prices in the United States – primarily

[19] See Adam (2011) or Arndt (2013) for macroeconomic models of the simulated effects of external food prices shocks, allowing for equilibrium adjustment in exchange rates.

through ethanol markets and by induced changes in farm input costs for fertilizer and fuel[20] – may differ dramatically from those that influence maize prices in low-income agrarian countries in Africa or other low-income regions where transport costs may be the primary channel of influence.

Like several studies before ours, we find no statistically significant causal relationship from oil prices to maize prices on global markets. By contrast, there exist strong, long run equilibrium relationships between global and national prices in both fuel and maize markets. Global prices clearly transmit to national level markets, with fairly high rates of pass-through. Within countries, there are even stronger price transmission patterns, most of them conforming to the law of one price hypothesis that price adjustments in one market transmit one-for-one to others in long-run equilibrium, controlling for transport costs. Furthermore, domestic fuel markets transmit price increases quickly, with adjustments to a new long-run equilibrium typically taking place within just a few months. The transmission from global maize markets to domestic maize markets is considerably slower, likely owing to policy interventions and infrastructural bottlenecks that impede international arbitrage.

The estimates derived from these time series price analyses permit us to estimate the impact of an increase in global oil prices on local maize prices in sub-national markets across east Africa. We find clear evidence that global oil prices indeed exert some influence on sub-national maize prices across east Africa through transport cost effects. These effects can be significant. The average estimated local maize price elasticity with respect to the global crude oil price is 0.26, with the greatest effects felt in the most remote markets. This novel finding underscores the importance of considering the full food system, including post-harvest distribution networks and their associated costs, in thinking through the food security implications of global shocks.

The co-movement of grain and oil prices on global market can obscure the important role of transport costs in exacerbating the negative consequences of food price shocks. In the study markets farthest from coastal ports, fuel price increases put greater upward pressure on local maize prices than do maize prices at the port-of-entry. More generally, the elasticity of local market maize prices with respect to global oil prices increases with distance from port of entry.

This finding has important policy implications. For landlocked regions of the low-income world, policies to mitigate the negative consequences of grain price shocks by directly intervening in both transport and grain markets, rather than just the latter, are more likely to achieve the desired food security objectives. Increased high-level attention to global food security tends to focus on farm-level productivity growth and on safety nets for poor consumers. Although these are clearly high priorities, so too is it essential to increase efficiency in the post-harvest systems – including liquid fuels and transport – that

[20] Mitchell (2008) reports that in 2007, combined chemical, energy and fertilizer costs accounted for 34% of maize production costs in the United States and these costs move sharply in response to oil prices.

deliver food to rapidly urbanizing populations from both domestic farmers and international markets (Gómez et al. 2011).

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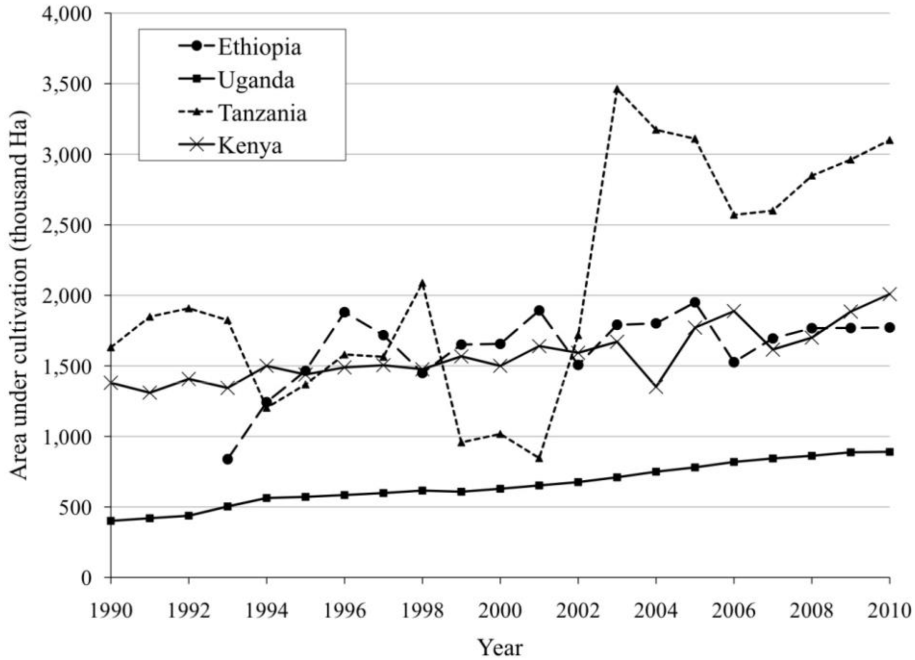
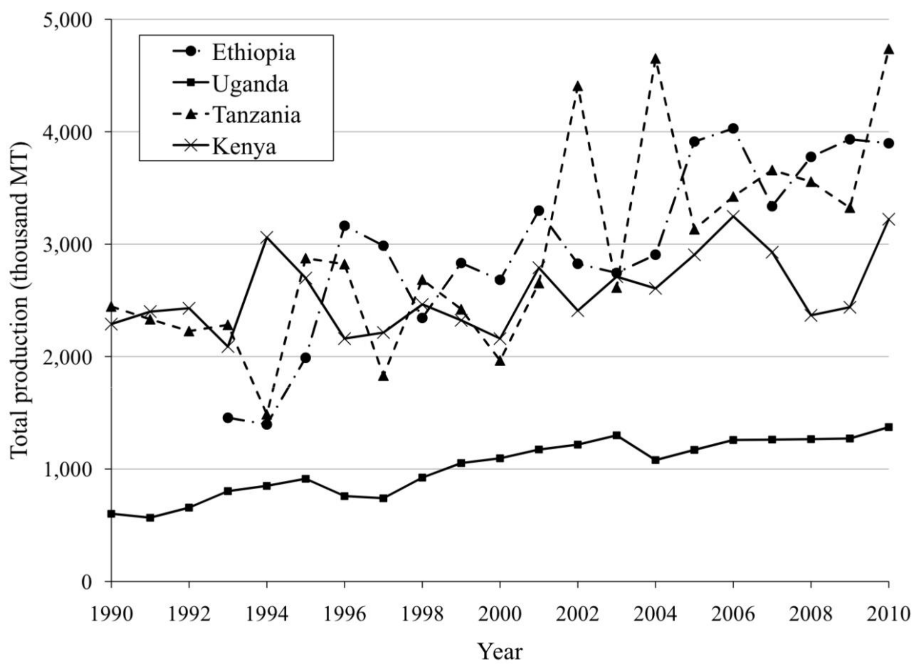
Figure 1. Maize, cultivated area, 1990-2010 (Ha)



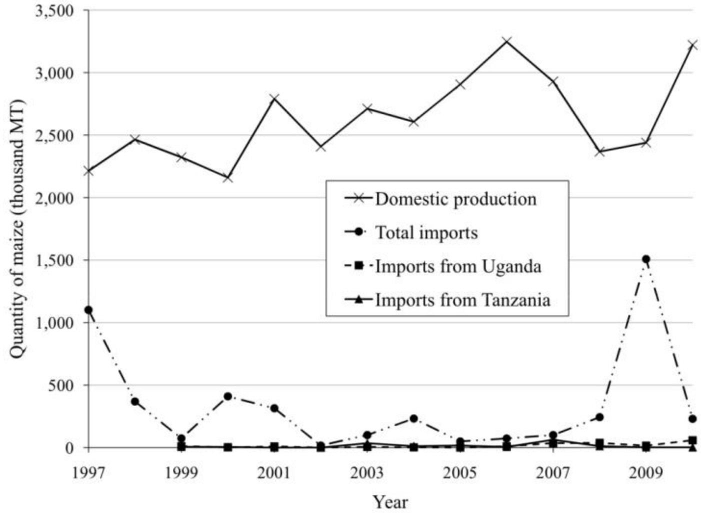
Data source: FAOStat

Figure 2. Maize output, 1990-2010 (MT)



Data source: FAOStat

Figure 3. Maize imports and production in Kenya, 1997-2010



Data source: FAOStat

Figure 4. Subnational study market locations

Figure 5. Global Market Maize and Oil prices, 2000-2012 (Nominal)

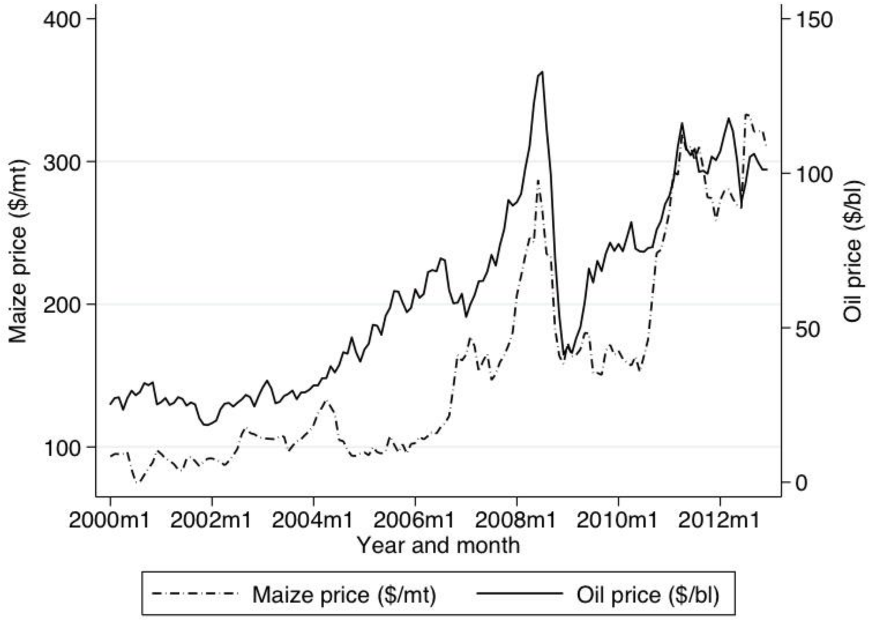


Figure 6. Global maize prices and maize prices in Addis Ababa, ET, 2000-2012

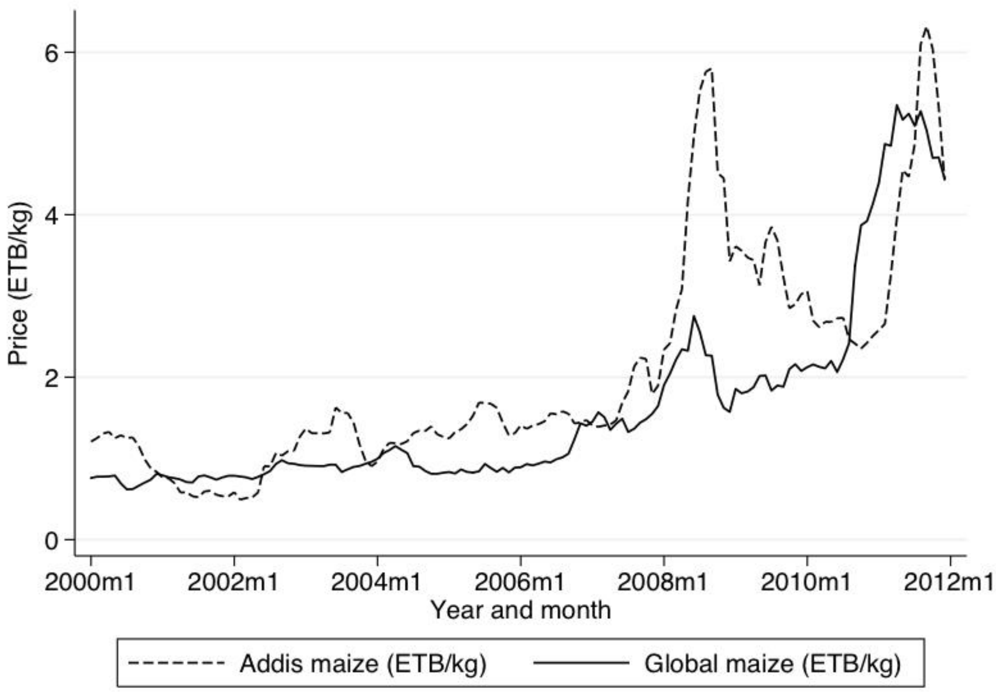


Figure 7. Global maize prices and maize prices in Mombasa, KY, 2000-2011

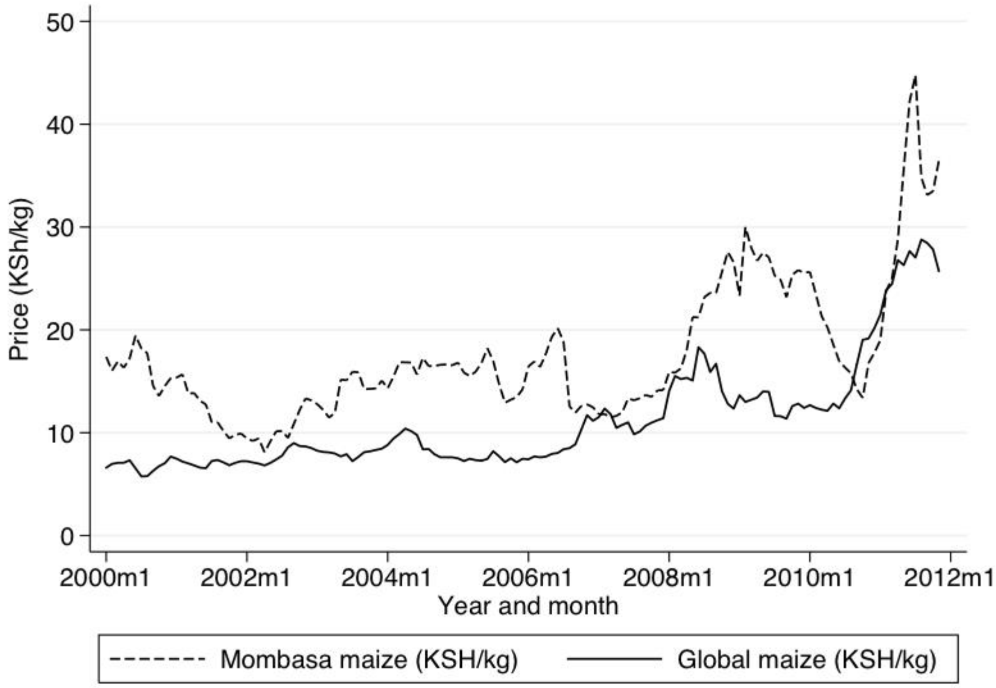


Figure 8. Global maize prices and maize prices in Dar es Salaam, TZ, 2000-2011

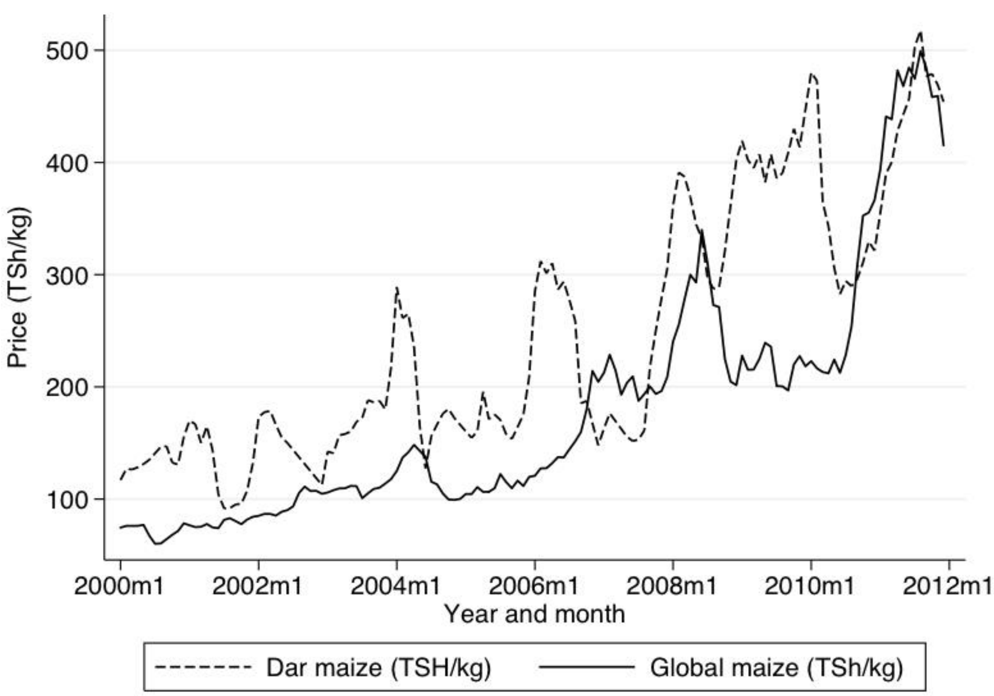


Figure 9. Global maize prices and maize prices in Kampala, UG, 2000-2012

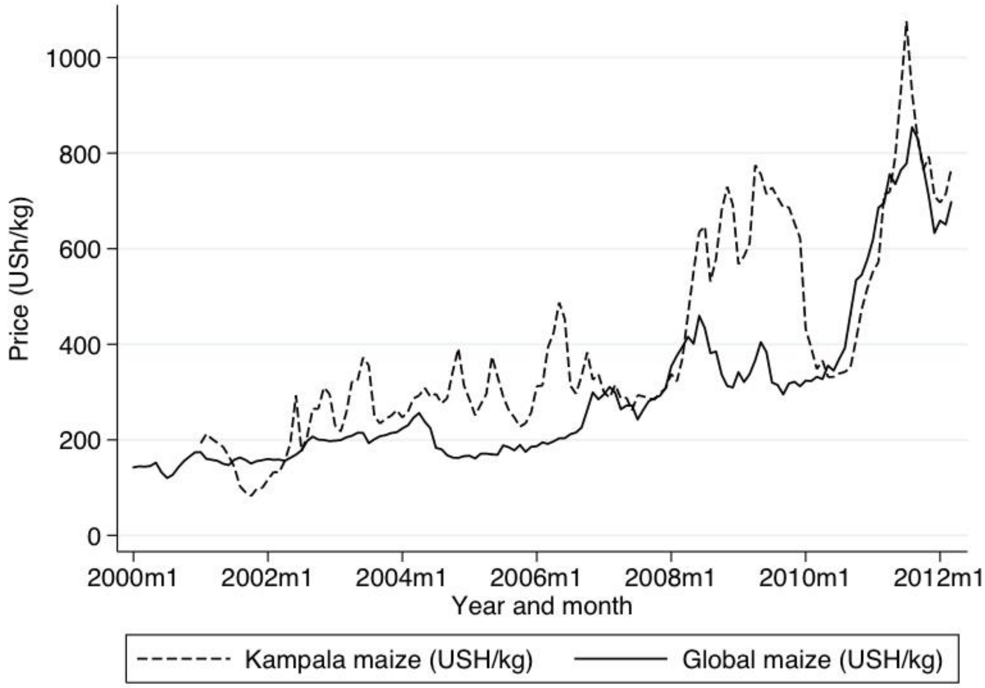


Figure 10. Global oil prices and fuel prices in Addis Ababa, ET, 2000-2012

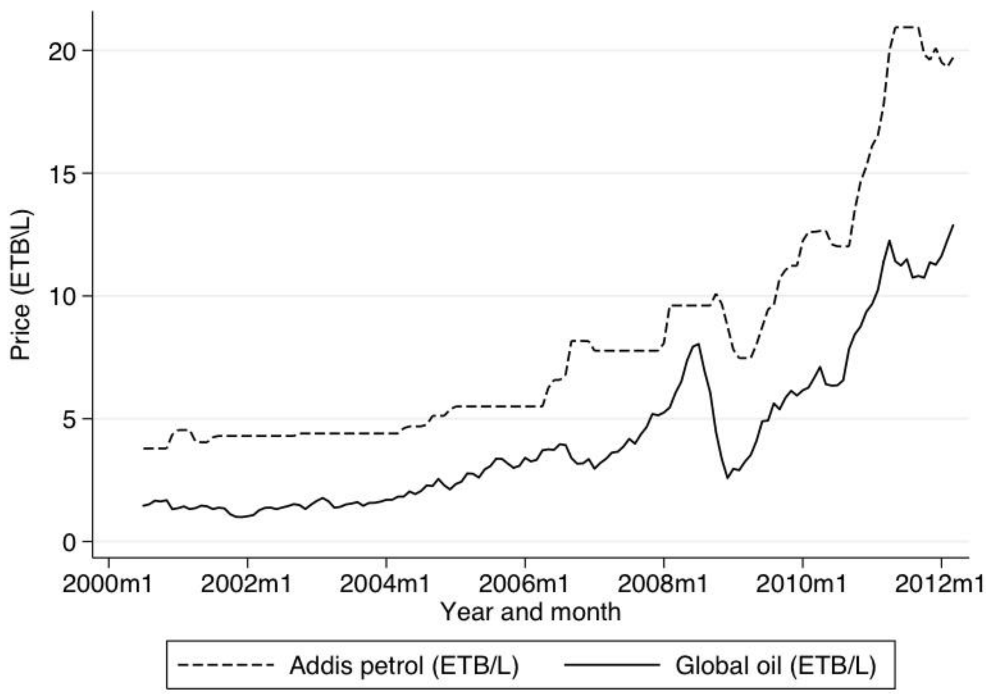


Figure 11. Global oil prices and fuel prices in Mombasa, KY, 1998-2012

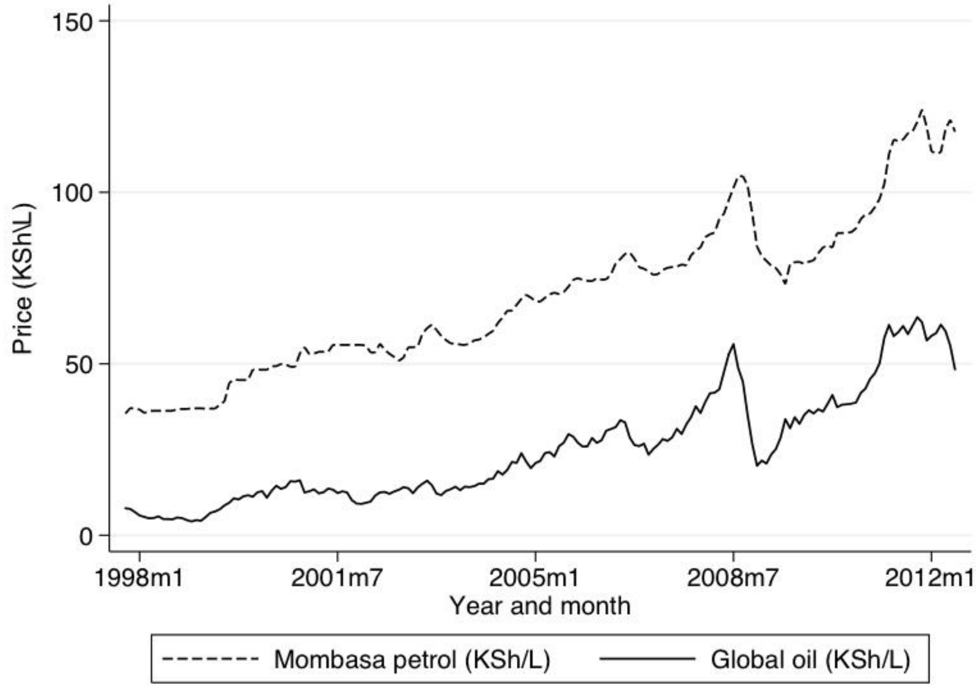


Figure 12. Global oil prices and fuel prices in Dar es Salaam, TZ, 2002-2012

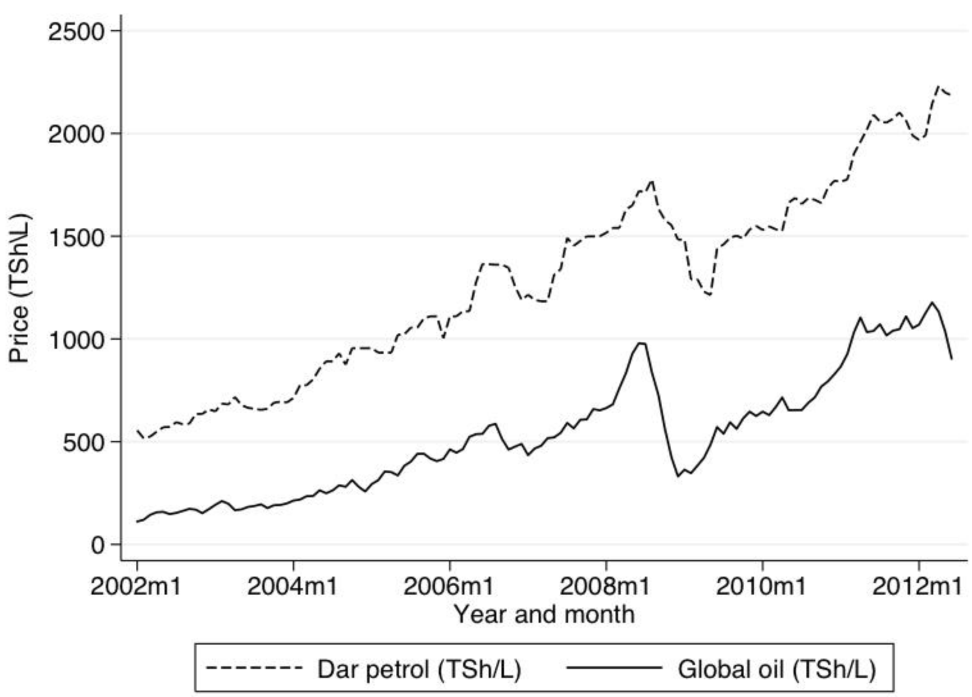


Figure 13. Global oil prices and fuel prices in Kampala, UG, 1998-2012

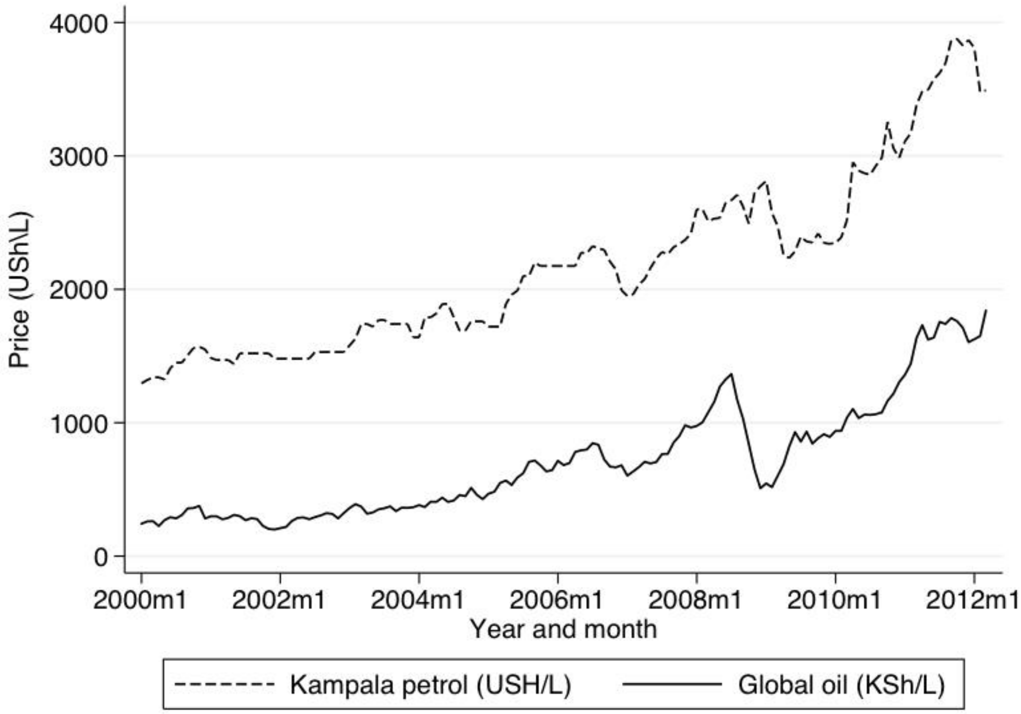


Figure 14. Diagram of Empirical Strategy

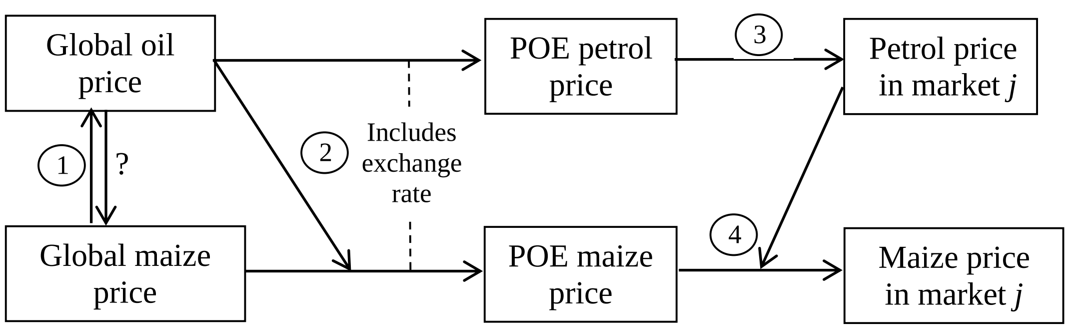


Figure 15. Global Maize and Oil prices, Oct 2006 – Nov 2012 (Nominal)

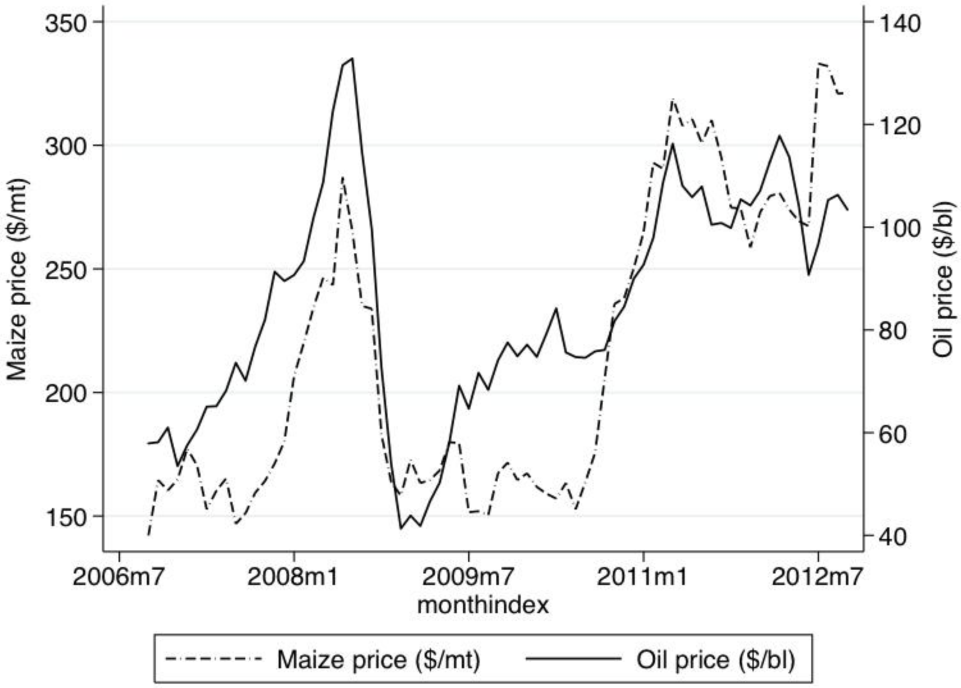


Figure 16. Normalized, average residuals by month from the first-stage ECM results, POE maize

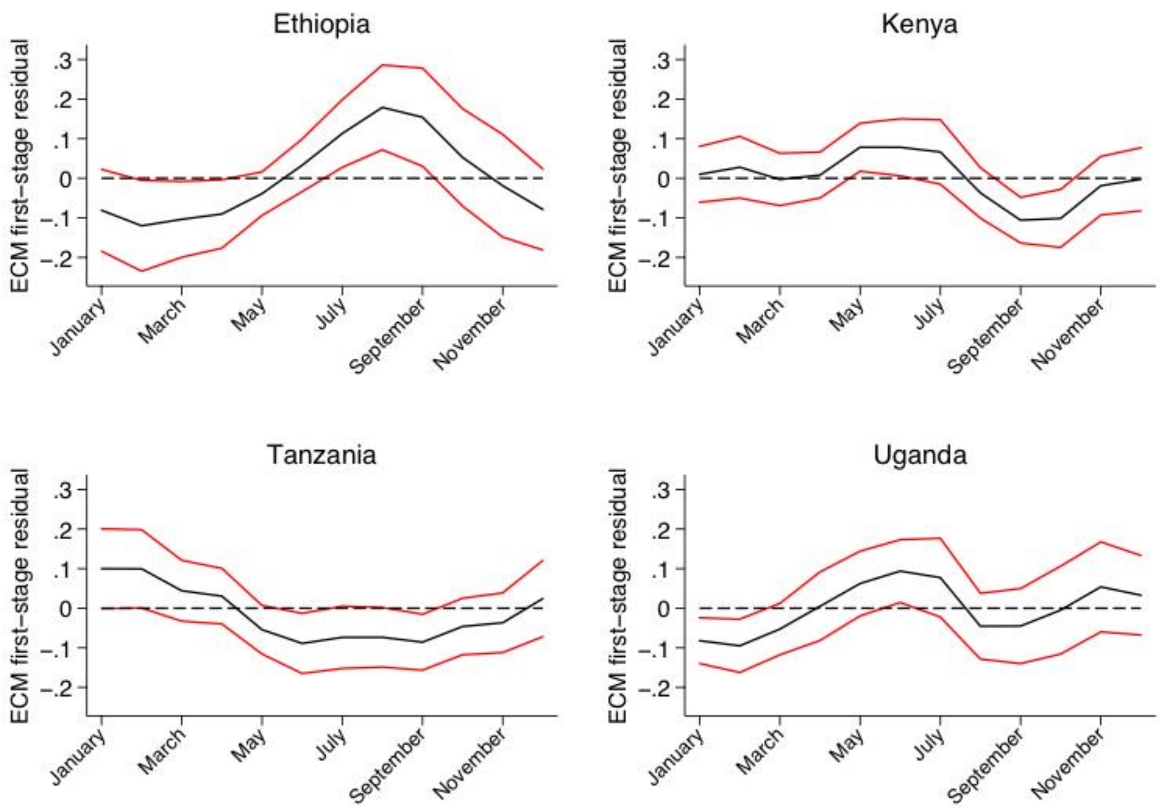


Figure 16. Estimated maize price elasticities with respect to global oil prices, as a function of distance from port of entry

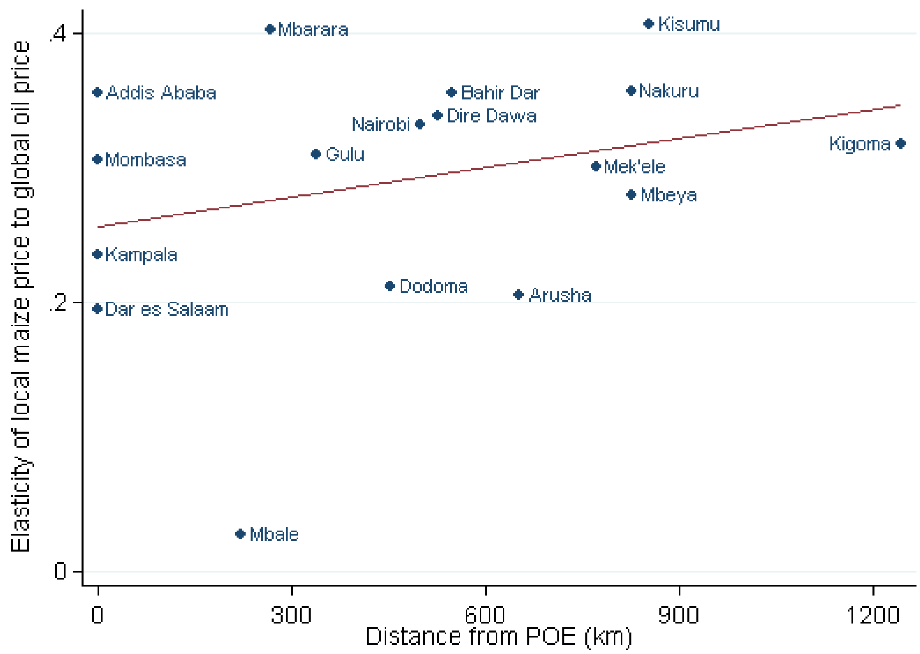


Figure 17. Estimated maize price elasticities with respect to global maize prices, as a function of distance from market closest to domestic breadbasket zone

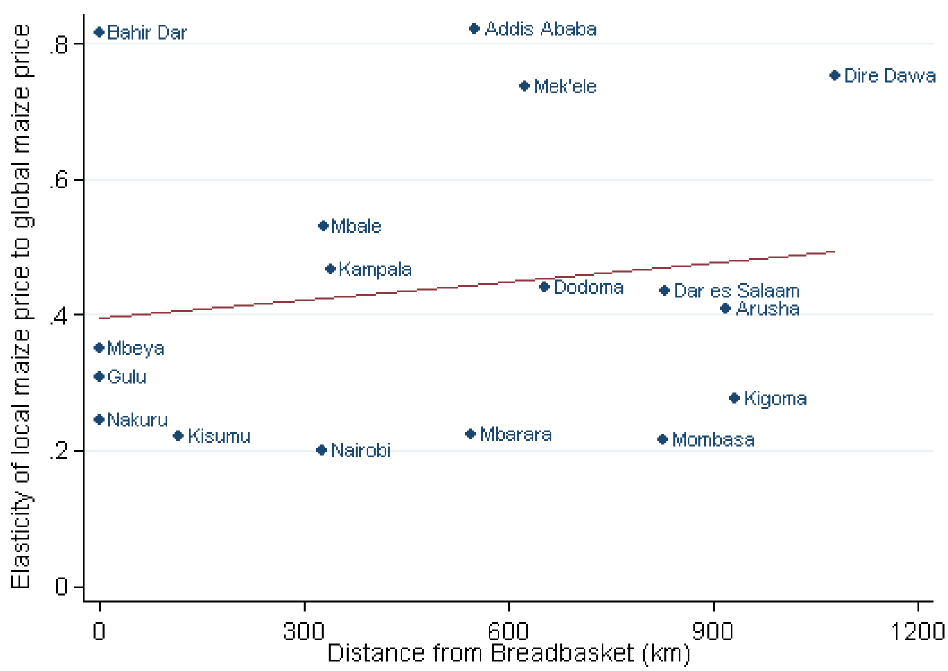


Table 1. Hectares under cultivation, by crop, 2007-2010

	Ethiopia	Kenya	Tanzania	Uganda
Area ('000 Ha)				
Maize	1,751	1,802	2,878	871
Other cereals	7,214	432	1,956	920
Fruit	90	188	814	1,835
Pulses	1,486	1,149	1,542	1,106
Tubers	803	261	1,542	1,102
Vegetables	368	140	310	188
Total	11,700	3,972	9,042	6,022
Area (average %)				
Maize	15.0%	45.4%	31.9%	14.5%
Other cereals	61.6%	10.8%	21.6%	15.3%
Fruit	0.8%	4.7%	9.0%	30.5%
Pulses	12.7%	29.0%	17.1%	18.4%
Tubers	6.9%	6.6%	17.0%	18.3%
Vegetables	3.1%	3.5%	3.4%	3.1%

Notes: Data are from FAOSTAT; Totals and percentages reflect only the total hectarage for the listed categories of crops; data are averages for years 2007-2010

Table 2. Maize net imports, 2000-2010

Country	Mean	Min	Max
Quantity (Metric Tons)			
Ethiopia	22,236	-9,659	59,599
Kenya	295,493	-13,711	1,502,523
Tanzania	18,690	-88,937	272,193
Uganda	-21,366	-125,857	34,371
Net Imports as % Production			
Ethiopia	0.6%	-0.3%	1.5%
Kenya	11.7%	-0.6%	61.6%
Tanzania	0.5%	-3.0%	8.0%
Uganda	-1.6%	-9.2%	3.2%

Data from FAOStat

Table 3. Within-country maize price comparisons, 2000-2012

Country	Market	Average price	Lowest price in country? Count	Frequency (%)
Ethiopia	Bahir Dar	1.92	107	73.8
	Addis Ababa*	2.04	26	17.9
	M'ekele	2.35	2	1.4
	Dire Dawa	2.42	10	6.9
Kenya	Eldoret/Nakuru	16.05	100	68.5
	Mombasa*	17.58	31	21.2
	Kisumu	18.45	12	8.2
	Nairobi	18.53	3	2.1
Tanzania	Mbeya	176.4	124	73.8
	Arusha	216.3	18	10.7
	Dodoma	222.3	13	7.7
	Dar es Salaam*	231.8	0	0.0
	Kigoma	234.3	13	7.7
Uganda	Gulu	213.2	76	71.7
	Mbale	265.8	9	8.5
	Kampala*	283.0	5	4.7
	Mbarara	302.2	16	15.1

Notes: Average prices are nominal, in local currencies; * indicates port-of-entry market; Uganda comparisons are for 2001-2008 due to data limitations

Table 4. Within-country fuel price comparisons, 2000-2012

Country	Market	Average price	Lowest price in country? Count	Frequency (%)
Ethiopia	Addis Ababa*	8.14	29	20.6
	Dire Dawa	8.20	99	70.2
	Bahir Dar	8.31	13	9.2
	M'ekele	8.33	0	0.0
Kenya	Mombasa*	67.95	69	40.4
	Eldoret/Nakuru	68.24	43	25.1
	Kisumu	68.82	43	25.1
	Nairobi	69.64	16	9.4
Tanzania	Dar es Salaam*	1282.60	79	61.7
	Dodoma	1301.53	33	25.8
	Arusha	1319.89	14	10.9
	Mbeya	1353.74	0	0.0
	Kigoma	1438.15	2	1.6
Uganda	Mbale	2167.91	86	57.3
	Kampala*	2175.71	58	38.7
	Mbarara	2219.91	4	2.7
	Gulu	2258.21	2	1.3

Notes: Average prices are nominal, in local currencies; * indicates port-of-entry market; both markets assigned lowest price designation in the event of a tie

Table 5. VAR results, global oil and maize prices (Nominal)

	(1) Jan 2000 – Oct 2012	(2) Oct 2006 – Oct 2012
Oil price equation		
LD.Oil price ($/bl)	0.324***	0.376***
	(0.0775)	(0.110)
LD.Maize price ($/mt)	0.110***	0.107**
	(0.0347)	(0.0481)
Constant	0.167	0.0873
	(0.391)	(0.730)
Maize price equation		
LD.Oil price ($/bl)	-0.0221	0.00121
	(0.195)	(0.300)
LD.Maize price ($/mt)	0.141	0.122
	(0.0874)	(0.131)
Constant	1.316	2.391
	(0.986)	(1.994)
N	154	73
R^2 oil equation	0.230	0.295
R^2 maize equation	0.0189	0.0149

Notes: standard errors in parentheses below coefficients; ***sig at 1%, ** sig at 5%, * sig at 10%; Price data from World Bank GEM Commodity Database; "D" is difference; "LD" is lagged difference

Table 6. POE fuel and global oil, first-stage ECM results

	Ethiopia	Kenya	Tanzania	Uganda
Global oil ($/bl)	0.053	0.621	8.667	14.507
	0.004	0.014	0.451	0.531
Exchange rate (Local/$)	1.194	0.792	1.262	1.182
	0.041	0.059	0.069	0.06
Constant	-7.322	-22.018	-839.344	-911.665
	0.325	4.251	66.468	104.065
R^2	0.955	0.94	0.96	0.94
N	141	177	126	147
Pass-through elasticity (oil)	0.380	0.463	0.435	0.383
Pass-through elasticity (ER)	1.519	0.854	1.219	1.036
Mean dep. variable	8.14	69.55	1282.60	2175.71

Notes: first-stage error correction results; dependent variable is the nominal price of retail petrol in the POE market of each country

Table 7. POE fuel and global oil, second-stage asymmetric ECM results

	Ethiopia	Kenya	Tanzania	Uganda
L.ECT^{neg}	-0.187***	-0.140***	-0.562***	-0.298***
L.ECT^{pos}	-0.132***	-0.144***	-0.097	-0.186***
D.Domestic CPI	0.013	0.192***	-4.804	2.62
LD.POE fuel (Local/L)	0.360***	0.203***	0.023	0.180**
LD.Global oil ($/bl)	0.008	0.164***	1.035	-1.172
LD.ER (Local/$)	0.177	0.305***	-0.024	0.270*
LD.Domestic CPI	0.001	-0.022	-1.853	-0.400
R^2	0.51	0.65	0.36	0.25
N	139	145	121	145
F test: ECM asymmetry (p-val)	0.447	0.937	0.001	0.24
Mean POE price (Local/L)	7.90	67.95	1240.75	2146.19

Notes: dependent variable is the change in nominal POE fuel price; *** sig at 1%, ** sig at 5%, * sig at 10%; regressions span 2000-2012 for KY and UG, 2002-2011 for TZ; ECT is the residual from the first stage regression of POE price on global price and a constants; ER is "exchange rate"; ER and CPI from IMF IFS database

Table 8. POE maize and global maize, first-stage ECM results

	Ethiopia	Kenya	Tanzania	Uganda
Global maize ($/mt)	0.0115	0.0260	0.593	1.201
	(0.00257)	(0.0137)	(0.191)	(0.414)
Global oil ($/bl)	0.0129	0.0960	0.367	1.546
	(0.00445)	(0.0298)	(0.406)	(0.779)
Exchange rate (Local/$)	0.0408	0.491	0.246	0.272
	(0.0383)	(0.0707)	(0.0435)	(0.0557)
Constant	-0.779	-29.13	-146.5	-408.6
	(0.246)	(5.280)	(35.85)	(89.54)
N	144	143	144	135
R^2	0.721	0.604	0.692	0.682
Pass-through elasticity (maize)	0.823	0.215	0.352	0.467
Pass-through elasticity (oil)	0.356	0.306	0.0843	0.235
Pass-through elasticity (ER)	0.202	2.140	1.162	1.334
Mean dep. variable	2.039	17.54	244.6	394.4

Notes: dependent variable is nominal POE maize price; results are OLS coefficients; standard errors are below estimates; dependent variable is the nominal wholesale price of maize in the POE market of each country

Table 9. POE maize and global maize and oil, second-stage asymmetric ECM results

	(1) Ethiopia	(2) Kenya	(3) Tanzania	(4) Uganda
L.ECT^{neg}	-0.0616	-0.0467	-0.0885*	-0.116
	(0.0509)	(0.0602)	(0.0490)	(0.0755)
L.ECT^{pos}	-0.202***	-0.178***	-0.136***	-0.194***
	(0.0393)	(0.0508)	(0.0502)	(0.0551)
D.Domestic CPI	0.0354***	0.184**	3.856**	4.411
	(0.00636)	(0.0794)	(1.761)	(3.326)
LD.POE maize (Local/L)	0.130	0.266***	0.412***	0.197*
	(0.0911)	(0.0814)	(0.109)	(0.114)
LD2.POE maize (Local/L)			-0.0886	0.103
			(0.0890)	(0.0911)
LD.Global maize ($/mt)	-0.00411**	0.0286*	-0.300	0.175
	(0.00204)	(0.0155)	(0.271)	(0.663)
LD2.Global maize ($/mt)			0.0771	0.280
			(0.196)	(0.467)
LD.Global oil ($/bl)	0.00109	-0.0396	-0.437	-0.769
	(0.00419)	(0.0307)	(0.529)	(1.222)
LD2.Global oil ($/bl)			0.317	0.425
			(0.439)	(1.012)
LD.ER Local/USD	-0.0286	0.145	-0.0362	-0.114
	(0.0786)	(0.111)	(0.138)	(0.123)
LD2.ER Local/USD			-0.0568	0.176
			(0.112)	(0.115)
LD.Domestic CPI	-0.00300	0.0347	-0.309	5.752
	(0.00634)	(0.0834)	(2.104)	(3.694)
LD.2Domestic CPI			0.787	-7.128**
			(1.832)	(3.056)
N	142	141	141	132
R^2	0.473	0.226	0.268	0.250
F test: ECM asymmetry (p-val)	0.0309	0.105	0.520	0.410
Mean POE price (Local/L)	2.039	17.54	244.6	394.4

Notes: dependent variable is the change in nominal POE maize price; standard errors in parentheses; *** sig at 1%, ** sig at 5%, * sig at 10%; regressions span 2000-2012 for ET, KY, and UG, 2002-2011 for TZ; ECT is the residual from the first stage regression; ER is "exchange rate"; ER and CPI from IMF IFS database

Table 10. Within-country fuel price transmission, ECM stage 1

Country	Market	POE fuel price	Constant	R^2	N	Pass-through elasticity
Ethiopia	Bahir Dar	1.034	-0.108	0.996	141	1.013
	Dire Dawa	1.099	-0.752	0.998	141	1.092
	M'ekele	1.06	-0.304	0.998	141	1.037
Kenya	Kisumu	0.972	2.790	0.988	171	0.959
	Nairobi	0.977	3.271	0.991	171	0.953
	Eldoret/Nakuru	1.001	0.244	0.992	171	0.996
Tanzania	Arusha	1.015	17.470	0.984	126	0.987
	Dodoma	1.023	-10.941	0.990	126	1.008
	Kigoma	1.114	9.474	0.980	126	0.993
	Mbeya	1.054	1.358	0.990	126	0.999
Uganda	Gulu	1.027	23.772	0.992	147	0.989
	Mbale	1.012	-33.272	0.993	147	1.015
	Mbarara	1.010	21.820	0.994	147	0.990

Notes: Prices are nominal, in local currencies

Table 11. Fuel price transmission within each study country, asymmetric ECM stage 2, 2000-2012 (with variable coverage)

	(1) ET Bahir Dar	(2) ET Dire Dawa	(3) ET Mek'ele	(4) KY Nairobi	(5) KY Kisumu	(6) KY Eldoret/ Nakuru	(7) TZ Arusha	(8) TZ Dodoma	(9) TZ Kigoma	(10) TZ Mbeya	(11) UG Gulu	(12) UG Mbale	(13) UG Mbarara
L.ECT^{neg}	-0.626***	-0.309	-0.503**	-0.220	-0.104	-0.323**	-0.502***	-0.430***	-0.644***	-0.488***	-0.508***	-0.737***	-0.461**
	(0.222)	(0.239)	(0.243)	(0.156)	(0.0846)	(0.134)	(0.165)	(0.158)	(0.182)	(0.162)	(0.176)	(0.224)	(0.192)
L.ECT^{pos}	-0.173	-0.150	-0.187	0.0743	0.116	-0.264**	-0.287*	-0.273	-0.261	-0.323**	-0.000583	-0.404*	-0.110
	(0.170)	(0.290)	(0.220)	(0.127)	(0.105)	(0.114)	(0.166)	(0.201)	(0.159)	(0.160)	(0.150)	(0.220)	(0.177)
LD.POE fuel	0.517*	0.762*	0.658*	0.131	0.462***	0.453***	0.387*	0.241*	0.0978	0.0979	0.719***	0.414**	0.342**
	(0.295)	(0.407)	(0.349)	(0.128)	(0.120)	(0.128)	(0.221)	(0.127)	(0.458)	(0.129)	(0.157)	(0.175)	(0.166)
LD2.POE fuel	-0.142	-0.471	-0.289				-0.252**		0.722				
	(0.229)	(0.293)	(0.262)				(0.123)		(0.689)				
LD3.POE fuel									-0.404				
									(0.504)				
LD4.POE fuel									0.0508				
									(0.145)				
LD.Own fuel	0.0219	-0.154	-0.0841	0.311**	-0.0532	-0.0525	-0.222	0.0671	0.173	0.106	-0.573***	-0.325**	-0.152
	(0.264)	(0.356)	(0.311)	(0.132)	(0.125)	(0.113)	(0.192)	(0.120)	(0.416)	(0.115)	(0.141)	(0.148)	(0.164)
LD2.Own fuel	0.106	0.412	0.238				0.142		-0.771				
	(0.193)	(0.252)	(0.226)				(0.101)		(0.582)				
LD3.Own fuel									0.628				
									(0.380)				
LD4.Own fuel									-0.163*				
									(0.0978)				
Constant				-0.000409									
				(0.234)									
Observations	138	138	138	175	175	175	123	124	121	124	145	145	145
R-squared	0.311	0.300	0.305	0.199	0.218	0.259	0.262	0.191	0.403	0.163	0.266	0.235	0.149
F test: ECM asymm (p-val)	0.0763	0.647	0.291	0.223	0.104	0.725	0.253	0.499	0.0318	0.428	0.0227	0.237	0.154

Notes: ***, **, * sig at 1%, 5%, 10%; all prices in nominal, local currency terms; ECT is the residual from a first stage regression of the sub-national market price on the POE price; "D" indicates difference, "LDX" indicates X-lagged difference

Table 12. Within-country maize price transmission, ECM stage 1

Country	Market	POE maize price	Own fuel price	Constant	R^2	N	Pass-through elasticities: POE maize	Pass-through elasticities: Own fuel
Ethiopia	Bahir Dar	0.934	0.001	0.009	0.98	138	0.991	0.005
	Dire Dawa	1.085	0.009	0.134	0.96	138	0.916	0.030
	M'ekele	1.030	-0.014	0.363	0.97	138	0.894	-0.046
Kenya	Kisumu	1.078	0.052	-4.361	0.95	143	1.028	0.209
	Nairobi	0.978	0.027	-0.677	0.93	143	0.928	0.109
	Eldoret/Nakuru	1.044	0.003	-2.526	0.89	143	1.144	0.014
Tanzania	Arusha	0.895	0.010	3.049	0.93	120	0.937	0.051
	Dodoma	1.010	0.007	-11.847	0.93	120	1.011	0.033
	Kigoma	0.667	0.090	-22.592	0.89	120	0.633	0.447
	Mbeya	0.636	0.046	-18.585	0.92	120	0.803	0.285
Uganda	Gulu	0.493	0.052	-19.906	0.90	131	0.659	0.410
	Mbale	1.051	-0.099	161.279	0.84	114	1.137	-0.618
	Mbarara	0.529	0.122	-75.516	0.65	91	0.482	0.761

Notes: Average prices are nominal, in local currencies; Uganda results are for 2001-2008 due to data limitations; Entries are OLS coefficients;

Table 13. Maize price transmission within each study country, asymmetric ECM stage 2, 2000-2012 (with variable coverage)

	(1) ET Bahir Dar	(2) ET Dire Dawa	(3) ET Mek'ele	(4) KY Kisumu	(5) KY Nairobi	(6) KY Eldoret/ Nakuru	(7) TZ Arusha	(8) TZ Dodoma	(9) TZ Kigoma	(10) TZ Mbeya	(11) UG Gulu	(12) UG Mbale	(13) UG Mbarara
$L.ECT^{neg}$	-0.921***	-0.796***	-0.275*	-0.521***	-0.468***	-0.413***	-0.404***	-0.188*	-0.293***	-0.337***	-0.188*	-0.353**	-0.236**
	(0.268)	(0.139)	(0.165)	(0.160)	(0.144)	(0.120)	(0.123)	(0.113)	(0.110)	(0.100)	(0.103)	(0.135)	(0.104)
$L.ECT^{pos}$	-0.381*	-0.397**	-0.273*	-0.510***	-0.320***	-0.341***	-0.419***	-0.385***	-0.313***	-0.419***	-0.164	0.0504	-0.396***
	(0.226)	(0.159)	(0.156)	(0.134)	(0.106)	(0.0949)	(0.117)	(0.102)	(0.0990)	(0.101)	(0.106)	(0.124)	(0.0899)
LD.POE maize	0.504*	0.330**	0.735**	0.154	0.252**	0.0660	0.151	0.131	0.367**	0.199***	0.195***	0.273**	0.312***
	(0.266)	(0.145)	(0.348)	(0.134)	(0.112)	(0.127)	(0.111)	(0.116)	(0.163)	(0.0746)	(0.0707)	(0.136)	(0.114)
LD2.POE maize	-0.245*		-0.208						-0.179				
	(0.141)		(0.381)						(0.114)				
LD3.POE maize			0.0428										
			(0.146)										
LD.Own maize	-0.0435	-0.0645	-0.447	0.293***	0.0628	0.278***	0.272***	0.382***	0.247	0.364***	-0.0353	-0.136	0.275***
	(0.250)	(0.102)	(0.315)	(0.107)	(0.0972)	(0.100)	(0.101)	(0.102)	(0.160)	(0.0872)	(0.113)	(0.117)	(0.0879)
LD2.Own maize	0.0490		0.658**						-0.0182				
	(0.129)		(0.321)						(0.106)				
LD3.Own maize			-0.329***										
			(0.118)										
LD.Own fuel	-0.0184	-0.0156	0.129**	0.143*	0.0765	0.0547	0.0272	0.00871	0.00580	-0.00958	-0.0106	-0.0250	0.00237
	(0.0547)	(0.0508)	(0.0609)	(0.0827)	(0.0703)	(0.0733)	(0.0350)	(0.0391)	(0.0530)	(0.0318)	(0.0334)	(0.0573)	(0.0697)
LD2.Own fuel	0.0428		-0.129						0.00126				
	(0.0499)		(0.0942)						(0.0338)				
LD3.Own fuel			0.0754										
			(0.0508)										
Constant	-0.0272												
	(0.0333)												
Observations	135	136	134	141	141	141	118	118	117	118	129	108	89
R-squared	0.379	0.406	0.448	0.327	0.319	0.261	0.285	0.348	0.243	0.354	0.148	0.130	0.443
F test: ECM asymmetry (p-val)	0.143	0.0326	0.993	0.955	0.377	0.622	0.925	0.174	0.886	0.553	0.868	0.0215	0.209

Notes: ***, **, * sig at 1%, 5%, 10%; all prices in nominal, local currency terms; ECT is the residual from a first stage regression of the sub-national market price on the POE price; "D" indicates difference, "LDX" indicates X-lagged difference

Table 14. Speed of adjustment:
Number of months required to complete 80% pass-through of global market price increase

		Fuel		Maize		Maize	Fuel-Maize
		Global-POE	POE-local	Global-POE	POE-local	Global-local	Global-local
Ctry	Market	(1)	(2)	(3)	(4)	(3) + (4)	(1) + (2) + (4)
ET	Addis Ababa	7.8		25.1		25.1	7.8
	Bahir Dar	7.8	1.6	25.1	0.6	25.8	10.1
	Dire Dawa	7.8	4.4	25.1	1.0	26.2	13.2
	M'ekele	7.8	2.3	25.1	5.0	30.2	15.1
KY	Kisumu	10.7	14.7	33.4	2.2	35.6	27.5
	Mombasa	10.7		33.4		33.4	10.7
	Nairobi	10.7	6.5	33.4	2.6	36.0	19.7
	Eldoret/Nakuru	10.7	4.1	33.4	3.0	36.5	17.8
TZ	Arusha	1.9	2.3	17.3	3.1	20.4	7.3
	Dar es Salaam	1.9		17.3		17.3	1.9
	Dodoma	1.9	2.9	17.3	7.7	25.0	12.5
	Kigoma	1.9	1.6	17.3	4.6	21.9	8.1
	Mbeya	1.9	2.4	17.3	3.9	21.2	8.2
UG	Gulu	4.5	2.3	13.1	7.7	20.8	14.5
	Kampala	4.5		13.1		13.1	4.5
	Mbale	4.5	1.2	13.1	3.7	16.8	9.4
	Mbarara	4.5	2.6	13.1	6.0	19.1	13.1

Notes: Authors' calculations based on results in Tables 7, 9, 11, and 13; entries show the number of months required for the smaller market price to reflect 80% pass through from an increase in the larger market price

Table 15. Cumulative pass-through elasticities

		(1)	(2)	(3)
		Elasticity of local maize prices with respect to…		
Country	Market	Global maize	Global oil	Exchange rate
Ethiopia	Addis Ababa	0.82	0.36	0.20
	Bahir Dar	0.82	0.35	0.21
	Dire Dawa	0.75	0.34	0.23
	M'ekele	0.74	0.30	0.11
	ET average	0.78	0.34	0.19
Kenya	Kisumu	0.22	0.41	2.37
	Mombasa	0.22	0.31	2.14
	Nairobi	0.20	0.33	2.07
	Nakuru	0.25	0.36	2.46
	KY average	0.22	0.35	2.26
Tanzania	Arusha	0.33	0.10	1.15
	Dar es Salaam	0.35	0.08	1.16
	Dodoma	0.36	0.10	1.22
	Kigoma	0.22	0.25	1.28
	Mbeya	0.28	0.19	1.28
	TZ average	0.31	0.14	1.22
Uganda	Gulu	0.31	0.31	1.30
	Kampala	0.47	0.24	1.33
	Mbale	0.53	0.03	0.87
	Mbarara	0.23	0.40	1.42
	UG average	0.38	0.24	1.23
Overall average		0.42	0.26	1.22

Notes: Authors' calculations from Tables 6, 8, 10, and 12

Table 16. Cumulative impacts of changes in global market prices and exchange rates

Scenario 1:	Only global oil price increase of 1%
Scenario 2:	Only global maize price increase of 1%
Scenario 3:	Global oil and global maize prices both increase 1%
Scenario 4:	Global oil, global maize, and exchange rate all increase 1%

		% change in local maize price			
Country	Market	Scen. 1	Scen. 2	Scen. 3	Scen. 4
Ethiopia	Addis Ababa	0.36	0.82	1.18	1.38
	Bahir Dar	0.35	0.82	1.17	1.38
	Dire Dawa	0.34	0.75	1.09	1.33
	M'ekele	0.30	0.74	1.04	1.14
Kenya	Kisumu	0.41	0.22	0.63	3.00
	Mombasa	0.31	0.22	0.52	2.66
	Nairobi	0.33	0.20	0.53	2.61
	Nakuru	0.36	0.25	0.60	3.06
Tanzania	Arusha	0.33	0.10	0.43	1.58
	Dar es Salaam	0.35	0.08	0.44	1.60
	Dodoma	0.36	0.10	0.46	1.67
	Kigoma	0.22	0.25	0.47	1.75
	Mbeya	0.28	0.19	0.47	1.75
Uganda	Gulu	0.31	0.31	0.62	1.92
	Kampala	0.24	0.47	0.70	2.04
	Mbale	0.03	0.53	0.56	1.42
	Mbarara	0.40	0.23	0.63	2.05

Notes: Price projections based on co-integrating vectors in earlier tables

Appendix A: Policy background in the study countries

The price of staple foods is a serious economic and political issue in developing countries. Price spikes can have pronounced effects on poverty rates, inflation, terms of trade, and fiscal balances, and can lead to political instability (Barrett 2013). The specter of such consequences commonly induces policymakers to intervene in an attempt to dampen pass-through from international markets (Ivanic et al. 2012).

In the 1990s, many commodity markets in Africa were liberalized as part of a general shift in the developing world away from planning and toward market determination of prices and trade flows. Since that time, governments in the four study countries have largely withdrawn from direct participation in the production or distribution of food and fuel. Nevertheless, there are policies in each study country that provide important context for the analysis to follow. In this section we give a brief overview of the relevant policy environment, and the role of maize in supporting food security, for each study country.

Ethiopia

The government of Ethiopia withdrew nearly all controls from maize markets during the period 1999-2002 (Rashid et al. 2010). The Ethiopian Grain Trade Enterprise (EGTE) still maintains strategic grain reserves that act as a buffer stock in the event of price spikes, but the price impacts of EGTE procurement are considered negligible (Tadesse & Guttormsen 2011). There is no set of well-documented import or export policies for the international maize trade. However, from the period 2008-2010 the government put in place a ban on exports, in response to global food price spikes.

Government control of the oil and fuel sector in Ethiopia is by far the most significant form of state intervention in any of the markets under study in this paper. The parastatal Ethiopian Petroleum Enterprise (EPE) is the exclusive importer of petrol and diesel, and the pump prices of both commodities are fixed by the Ministry of Trade and Industry (MoTI). This is potentially problematic for the analysis, because it suggests that observed fuel prices in Ethiopia are choice variables rather than the product of market forces. However, the government of Ethiopia lacks the resources to heavily subsidize a substantial fuel price subsidy for an extended length of time.

Kenya

The government is a significant player in the maize market, through the National Cereals Produce Board (NCPB), which buys and sells maize to address government food security objectives (Jayne et al. 2008). However, the private market remains highly competitive. In the period 2000-2004, the government of Kenya levied maize import tariffs ranging from 20-30%. For the last five years, maize imports from Uganda and Tanzania have not been taxed, but tariffs are 50% on imports from elsewhere.

Kenya is the only study country with a domestic oil refinery. By mandate, domestic refining of imported crude oil supplies 50% of consumer fuel products to Kenyan markets (Kojima et al. 2010). In 2011 price controls were implemented in petrol and diesel markets, with the government setting a maximum price of each product in each major market. However, over nearly all of the study period, prices were market-determined throughout the country.

Tanzania

Maize prices in Tanzania are primarily determined by market forces. The government is not heavily involved in the maize trade, although the Ministry of Agriculture maintains a strategic grain reserve for use in mitigating the effects of large shocks. The most significant maize policy in recent years has been a series of *ad hoc* export bans, implemented periodically since 2008, purportedly to drive down prices during periods of re-stocking reserves.

From 2000-2005 prices of fuel products in Tanzania were determined competitively. Since 2006, the Energy and Water Utilities Regulatory Authority (EWURA) has issued a cap on the prices of petrol, diesel, and kerosene, based on a publicly available formula. In 2011, a competitive auction was established to assign exclusive import rights to one company for each two-month period. This was primarily intended to reduce congestion at the ports by sequencing the activities of the major fuel importers. Most of our data pre-dates this policy change.

Uganda

Uganda is arguably the most liberalized market economy in east Africa. There are no price controls on maize, and no government organizations involved in production or distribution. There are no noteworthy import or export controls. In recent years, the World Food Program has procured substantial amounts of maize from Uganda for re-distribution within the region as food aid, which has occasionally put some upward pressure on prices.

Similarly, the market for petrol and diesel in Uganda is less regulated than in the other countries. Pump prices are competitively determined. Fuel products are imported via trucks from Kenya and Tanzania, and retail prices are generally higher than in those two countries. There are no import tariffs on oil products. Oil was discovered in Uganda in 2006. It is expected that in the next 5-10 years domestic oil production will come on-stream. Nevertheless, Uganda will likely be a price-take on fuel markets for decades to come.

Appendix B: Weak exogeneity of exchange rates

The exchange rate is an important component of the long-run relationship between nominal prices in POE markets and nominal prices in global markets. The framework in this paper treats the exchange rate as weakly exogenous to the estimated relationships. In essence, we assume that the nominal POE price of maize (fuel) is the only price that adjusts to disequilibrium in the stationary relationship between POE maize (fuel) and global maize (oil). Although the exchange rate is determined by a wide range of factors other than the prices of the commodities studied in this paper, this is likely a restrictive assumption, particularly when the prices of other traded commodities co-move with those of maize and oil. However, this assumption is essential if we are to focus on single-equation error-correction models for POE prices, rather than specify and estimate an accompanying full model of exchange rate determination. In this section we provide some evidence to assess how restrictive of an assumption this is.

Following Enders (2010), we estimate a full vector error correction system, for each country-commodity pair, using maximum likelihood (Johansen, 1991). For the POE maize models this system takes the following form:

(B1) $\Delta M_t^{POE} = \vartheta_1\left[M_{t-1}^{POE} - \beta_1 M_{t-1}^{G} - \beta_2 F_{t-1}^{G} - \beta_3 ER_{t-1} - \alpha\right] + \sum_{k=1}^{K}\{\delta_{5k-2}\Delta M_{t-k}^{POE} + \delta_{5k-1}\Delta M_{t-k}^{G} + \delta_{5k}\Delta F_{t-k}^{G} + \delta_{5k+1}\Delta ER_{t-k} + \delta_{5k+2}\Delta CPI_{t-k}\} + \nu_{1t}$

(B2) $\Delta M_t^{G} = \vartheta_2[M_{t-1}^{POE} - \beta_1 M_{t-1}^{G} - \beta_2 F_{t-1}^{G} - \beta_3 ER_{t-1} - \alpha] + \sum_{k=1}^{K}\{\gamma_{5k-2}\Delta M_{t-k}^{POE} + \gamma_{5k-1}\Delta M_{t-k}^{G} + \gamma_{5k}\Delta F_{t-k}^{G} + \gamma_{5k+1}\Delta ER_{t-k} + \gamma_{5k+2}\Delta CPI_{t-k}\} + \nu_{2t}$

(B3) $\Delta F_t^{G} = \vartheta_3[M_{t-1}^{POE} - \beta_1 M_{t-1}^{G} - \beta_2 F_{t-1}^{G} - \beta_3 ER_{t-1} - \alpha] + \sum_{k=1}^{K}\{\rho_{5k-2}\Delta M_{t-k}^{POE} + \rho_{5k-1}\Delta M_{t-k}^{G} + \rho_{5k}\Delta F_{t-k}^{G} + \rho_{5k+1}\Delta ER_{t-k} + \rho_{5k+2}\Delta CPI_{t-k}\} + \nu_{3t}$

(B4) $\Delta ER_t = \vartheta_4[M_{t-1}^{POE} - \beta_1 M_{t-1}^{G} - \beta_2 F_{t-1}^{G} - \beta_3 ER_{t-1} - \alpha] + \sum_{k=1}^{K}\{\tau_{5k-2}\Delta M_{t-k}^{POE} + \tau_{5k-1}\Delta M_{t-k}^{G} + \tau_{5k}\Delta F_{t-k}^{G} + \tau_{5k+1}\Delta ER_{t-k} + \tau_{5k+2}\Delta CPI_{t-k}\} + \nu_{4t}$

where all variables are as defined in Section 3, Greek letters are coefficients, and the ν_{it} terms, i=1,…4, are statistical error terms. The terms in square brackets are equivalent to the L.ECT terms from the two-stage estimation method employed in the main body of the paper. This specification is based on rank tests of cointegration, which indicate the presence of a single cointegrating vector with a constant in the long-run equation at either the 1% or 5% level for each country. Lag lengths correspond to those used in the main body of the paper.

The estimated coefficient vectors ($\vartheta_4, \boldsymbol{\tau}$) from the B4 equations are shown in Table B1. The $\hat{\vartheta}_4$ coefficient on L.ECT is shown in the first row of the column. The magnitude and statistical significance of this coefficient is a measure of the degree to which the exchange rate responds to lagged deviations from the long-run equilibrium relationship between the four price series (Enders, 2010). Only in Ethiopia is the exchange rate response statistically different from zero, and there only at the 10% level. Furthermore, this coefficient estimate is *positive*, which, if well-identified, would indicate that the nominal POE maize price adjustments we observe are an underestimate of the effects we would see in the absence of an exchange rate adjustment. Magnitudes of all estimated $\hat{\vartheta}_4$ coefficient coefficients are small: it would take more than 2 years for any of the exchange rates to fully absorb the influence of a deviation from long-run equilibrium. While this evidence is not based on a full exchange rate model and so must be interpreted with caution, it does demonstrate that the changes in global commodity prices that are so fundamental to POE maize price determination do not also generate large, rapid exchange rate adjustments that would be a significant challenge to identification of our core specifications.

We estimate a similar system for the global-POE fuel price equations, separately for each country:

(B5) $\Delta F_t^{POE} = \mu_1[F_{t-1}^{POE} - \varphi_1 F_{t-1}^G - \varphi_2 ER_{t-1} - \pi] + \sum_{k=1}^{K}\{\sigma_{4k-1}\Delta F_{t-k}^{POE} + \sigma_{4k}\Delta F_{t-k}^G + \sigma_{4k+1}\Delta ER_{t-k} + \sigma_{4k+2}\Delta CPI_{t-k}\} + \varepsilon_{1t}$

(B6) $\Delta F_t^G = \mu_2[F_{t-1}^{POE} - \varphi_1 F_{t-1}^G - \varphi_2 ER_{t-1} - \pi] + \sum_{k=1}^{K}\{\omega_{4k-1}\Delta F_{t-k}^{POE} + \omega_{4k}\Delta F_{t-k}^G + \omega_{4k+1}\Delta ER_{t-k} + \omega_{4k+2}\Delta CPI_{t-k}\} + \varepsilon_{2t}$

(B7) $\Delta ER_t = \mu_3[F_{t-1}^{POE} - \varphi_1 F_{t-1}^G - \varphi_2 ER_{t-1} - \pi] + \sum_{k=1}^{K}\{\partial_{4k-1}\Delta F_{t-k}^{POE} + \partial_{4k}\Delta F_{t-k}^G + \partial_{4k+1}\Delta ER_{t-k} + \partial_{4k+2}\Delta CPI_{t-k}\} + \varepsilon_{3t}$

where the term in square brackets represents the L.ECT term, Greek letters are coefficients, and the ε_{it} terms, i=1,…4, are statistical error. The estimated coefficient vectors ($\mu_3, \boldsymbol{\partial}$) from the B7 equations are shown in Table B2. In the case of fuel markets we see marginally significant exchange rate responses in Ethiopia and Kenya, though once again the magnitudes are small in absolute value. In Uganda and Tanzania, the exchange rate does not respond to deviations from the global oil - POE fuel price equilibrium.

The general message of this evidence is that while exchange rates are likely not exogenous to oil and maize price movements in the long run, there is little evidence in our data for large or sustained exchange rate adjustments in the estimated models. This is encouraging, as weak exogeneity of exchange rates is an important assumption underlying the two-step estimation method employed in the main body of the paper.

Table B1. Exchange rate response to Global-POE maize disequilibrium

	(1) ET maize	(2) KY maize	(3) TZ maize	(4) UG maize
L.ECT	0.0595*	0.0484	0.00661	0.0460
	(0.0350)	(0.0320)	(0.0189)	(0.0369)
LD.POE maize price	-0.0954	0.0762	0.0928	0.157*
	(0.0803)	(0.0691)	(0.0705)	(0.0802)
L2D.POE maize price			-0.0144	-0.133
			(0.0719)	(0.0839)
LD.Global oil price	0.00300	-0.0617**	-0.407	-1.177
	(0.00456)	(0.0274)	(0.376)	(0.975)
L2D.Global oil price			-0.469	-0.200
			(0.368)	(0.946)
LD.Global maize price	0.00289	0.0289**	0.0417	0.696*
	(0.00231)	(0.0134)	(0.160)	(0.410)
L2D.Global maize price			0.120	0.341
			(0.165)	(0.419)
LD.Exchange rate	0.135	0.215**	0.307***	0.444***
	(0.0863)	(0.0926)	(0.0948)	(0.102)
L2D.Exchange rate			-0.0479	-0.0743
			(0.0944)	(0.0973)
Observations	142	141	141	132
Exchange rate mean	10.12	76.44	1158	1907

Notes: dependent variable is change in exchange rate; standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table B2. Exchange rate response to Global oil - POE fuel price disequilibrium

	(1) ET fuel	(2) KY fuel	(3) TZ fuel	(4) UG fuel
L.ECT	-0.0441**	-0.0539*	-0.0111	0.0285
	(0.0223)	(0.0294)	(0.0112)	(0.0265)
LD.POE fuel price	0.0124	0.0633	0.00669	-0.0279
	(0.0521)	(0.0652)	(0.0329)	(0.0474)
LD.Global oil price	-0.00369	-0.0900***	-0.637*	-0.401
	(0.00436)	(0.0323)	(0.347)	(0.882)
LD.Exchange rate	0.0645	0.194**	0.295***	0.397***
	(0.0990)	(0.0776)	(0.0874)	(0.0849)
Observations	139	175	124	145
Exchange rate mean	10.36	75.03	1239	1907

Notes: dependent variable is change in exchange rate; standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Appendix C: Fertilizer prices

Detailed look at Kenya

Data on the global market prices of diammonium phosphate (DAP), the primary fertilizer product used in Kenya (Ariga and Jayne, 2009), are available from the World Bank GEM commodity database. Data are the average spot f.o.b. price of the standard size bulk DAP package in the US Gulf. Average monthly market prices of DAP in Nairobi, for the period January 2007 – November 2011, were provided by the Kenya National Bureau of Statistics. Monthly data from earlier years, or from other markets in Kenya, were not available.

Figure C1 shows the time series plot of global market oil prices (as defined in Section 3) and global market DAP prices for the period 1990-2012. While the series do appear to co-move, visual inspection does not reveal an immediate lag-leader relationship. The series are closely correlated: the correlation coefficient is 0.86 over the entire sample, and 0.70 in the period since October 2006. Figure C2 plots the Nairobi DAP price series against the global DAP price series, with the latter converted to KSh/MT using the monthly exchange rate. Co-movement is clear, though cointegration is not apparent without a formal test.

Over both the period 1990-2012 and 2007-2011, the ADF test cannot reject the stationarity null for the global market DAP prices in levels (at 10%) or first differences (at 1%), and the Phillips-Perron test indicates that the series is I(1). We therefore treat the series as I(1). Johansen tests indicate that global oil and global DAP prices are cointegrated, with a constant in the cointegrating equation. Joint estimation of the system, using maximum likelihood, shows that the oil price does not respond significantly (in economic or statistical terms) to deviations from the long run stationary relationship. Any causal relationship between the series runs from oil prices to DAP prices, not vice versa, just as one would expect. We therefore adopt the same two-step procedure that we used for the global-POE maize and oil price relationships, using OLS in both stages and treating the global oil price as weakly exogenous.

Results of the ECM linking global oil and global DAP prices are given in Tables C1 and C2. All coefficients have the expected sign. The estimate DAP-oil price elasticity is 0.84, very close to unity (Table C1). We cannot reject asymmetric adjustment back to the long-run at the 6% level, though adjustment is slow in all cases, on the order of 1 year for (relative) DAP price increases, and 2 years for (relative) oil price increases. In sum, over the period 1990-2012, global market oil price changes transmit to global market DAP prices, with near complete pass-through occurring after a period of 1-2 years.

Demonstrating a causal link between global DAP prices and Nairobi DAP prices is more difficult, because of the short time series for Nairobi. The Schwarz-Bayesian information criterion from a VAR of global DAP prices, Nairobi DAP prices, and Kenya exchange rates exhibits a sharp drop-off at two lags, and then a second drop-off at nine lags. Johansen tests at two month lags indicate that the series are not cointegrated, while Johansen tests at nine lags indicate a maximum of one cointegrating vector. However, the nine lag model is heavily over-parameterized (77 parameters, 153 data points). It seems plausible that the series are cointegrated, but that major price changes on global markets transmit infrequently to Nairobi prices, in accordance with seasonal bulk purchases in the run-up to the maize cultivation season. But with only five years of monthly data, this relationship is difficult to identify.

To make the most of the data without relying on a heavily parameterized nine lag error correction model, we estimate a VAR in first differences. Results are shown in Table C3.[21] While we cannot make causal inference based on these results, the estimates are reassuring. Lagged changes in global DAP prices and exchange rates are closely correlated with changes in Nairobi DAP prices. The global market DAP price co-moves only very weakly with lagged changes in Nairobi prices, and is not influenced by the Kenya exchange rate. Lastly, the exchange rate is invariant to changes in either fertilizer price series. The average elasticity of

[21] Including the global oil price in the VAR does not substantially change results, and the oil price has no impact on Nairobi fertilizer prices separate from that mediated through global DAP prices. Results available upon request.

the nominal Nairobi DAP price with respect to the nominal global DAP price is 0.56, and the average exchange rate elasticity is 1.55.

Finally, because we do not have data on DAP prices at sub-national markets in Kenya, we cannot measure the transmission of fertilizer prices throughout the country. This is a potentially substantial shortcoming, given that the price spread between average annual prices in Mombasa and Eldoret/Nakuru fell substantially over the period 1990-2008 (Ariga and Jayne 2009). Nevertheless, we re-estimate a set of error correction models similar to those in equations 7 and 8 with the Nairobi DAP price as an additional independent variable.

Results for Kisumu, Nairobi, and Eldoret/Nakuru are shown in Tables C4 and C5. With such a short time series, it is unlikely that these estimates are very robust. However, it is noteworthy that at least over the period 2007-2011, DAP price increases negatively impact price spreads between POE maize and local maize (Table 20). Furthermore, in Table 21 we see that DAP prices play essentially no role in the short-run dynamics of local maize prices. As tenuous as these results are, it is reassuring that they give us even less reason to suspect that the core Kenya results are driven by increases in production costs.

Including fertilizer prices in the global-POE equations for all study countries

An alternative way to test whether fertilizer costs impact maize prices in study countries, independently of their impact on the global market price of maize, is to include the price of fertilizer on global markets directly in the error correction models linking the POE prices of maize and fuel to global market prices. Although fertilizer use rates were not significant in Ethiopia, Tanzania, and Uganda during the study period, we implement this robustness check for all study countries. As before, we are interested only in the magnitude of the fertilizer coefficient in the first-stage regressions, because the standard errors are not valid in these regressions. In the second stage equations we are interested in both coefficient magnitude and statistical significance.

Tables C6 and C8 show the first stage and second stage ECM results, respectively, for POE fuel equations with the global DAP price included. As one would expect, the fertilizer price has neither an economically nor a statistically significant impact on the POE fuel price in any study country.

Tables C7 and C9 show similar results for the POE maize equations. Lag lengths in the second stage equations are matched to those from the main study. In the short run dynamics (Table C9), which persist for roughly 1-2 years on average, the global fertilizer price has no economic or statistically significant effect on POE maize prices in any of the study countries. In the long run equations (Table C7), DAP does not matter in the equations for Kenya, Tanzania, and Uganda. The coefficient magnitudes on global fertilizer prices for these countries are only a small fraction of those on the global oil price and the exchange rates. Only in Ethiopia does the fertilizer price appear to have a sizable long-run impact on the POE maize price (Table C7). While this could be reflective of a real price effect,[22] it is likely also due in part to collinearity between the global DAP price and the global oil price. On balance, global fertilizer prices have very little effect on POE fuel and maize prices in east Africa after conditioning on global maize and global oil prices.

[22] For decades, the government of Ethiopia has intervened to increase fertilizer use by farmers, though with very limited success. See Spielman et al. (2011).

Figure C1. Global Maize and Fertilizer prices, 1990-2012 (Nominal)

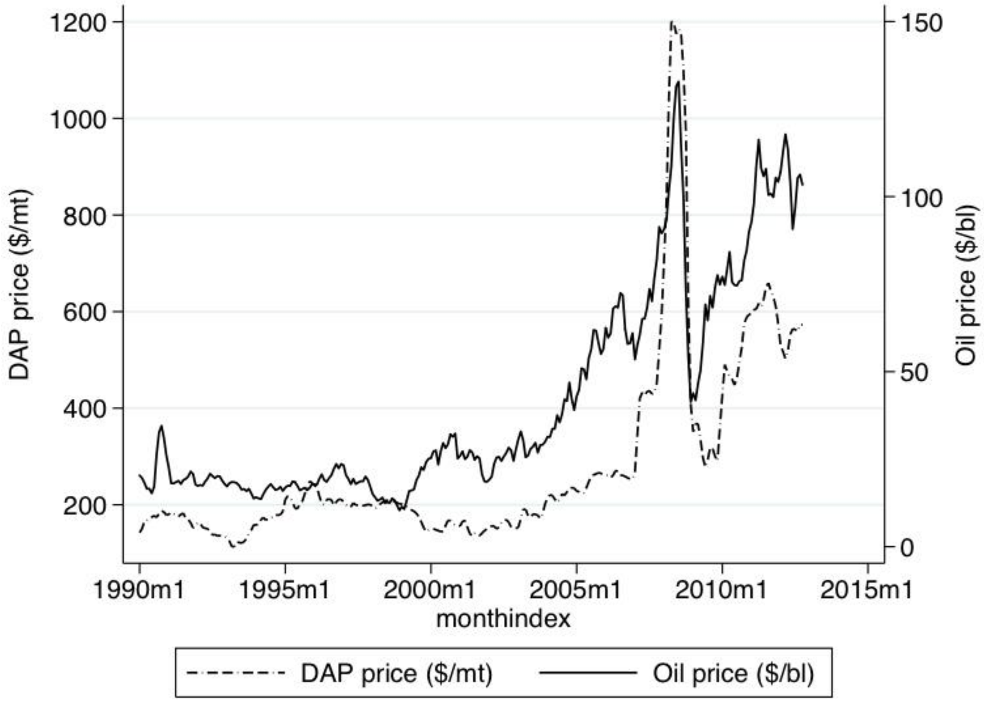


Figure C2. Global DAP prices and DAP prices in Nairobi, KY, 2007-2011 (Nominal)

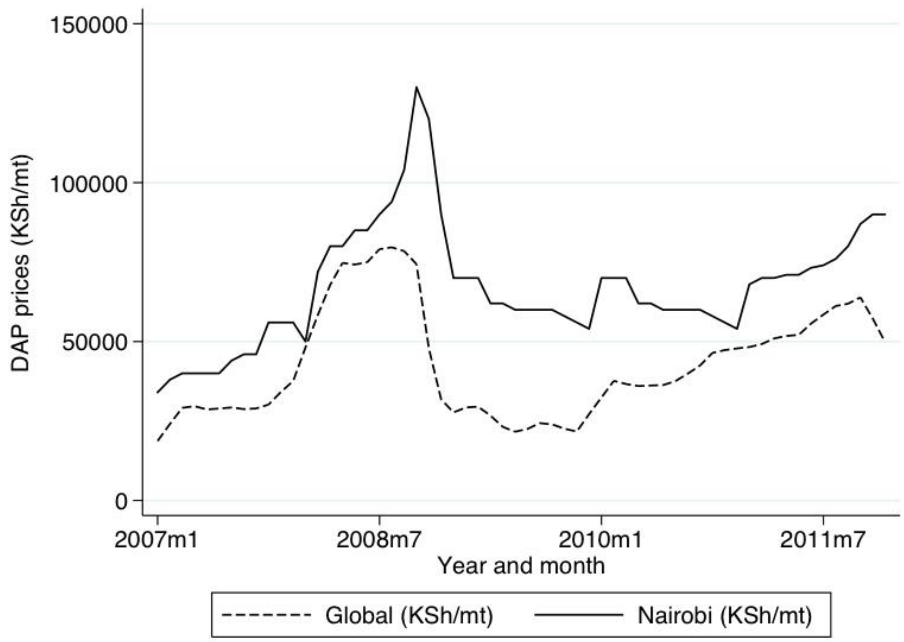


Table C1. Global DAP and global oil, first stage ECM results, 1990-2012

	Dep var: global DAP price
Oil price ($/bl)	5.756
	0.208
Constant	45.017
	10.739
R^2	0.737
N	274
DAP price elasticity w.r.t. oil price	0.841

Notes: first-stage error correction results from OLS regression; standard errors below coefficient estimates; dep var is nominal global market DAP price ($/mt)

Table C2. Global DAP and global oil, second stage ECM results

	Symmetric	Asymmetric
L.ECT	-0.073***	
	0.014	
$L.ECT^{neg}$		-0.035
		0.024
$L.ECT^{pos}$		-0.089***
		0.016
LD.DAP price ($/mt)	0.656***	0.655***
	0.042	0.042
LD.Oil price ($/bl)	1.349***	1.396***
	0.367	0.366
R^2	0.604	0.609
N	272	272
F test: asymmetric (p-val)		0.058

Notes: dependent variable is change in DAP price; *** sig at 1%, ** sig at 5%, * sig at 10%; all prices in nominal, local currency terms; ECT is the residual from a first stage regression of the DAP price on the oil price; "LD" indicates lagged difference

Table C3. VAR: Nairobi DAP price, global DAP price, KSh exchange rate (2007-2011)

	D.Nairobi DAP	D.Global DAP	D.ER
LD.Nairobi DAP (KSh/mt)	0.001	-0.003***	-0.00005
	0.111	0.001	0.00004
LD.Global DAP ($/mt)	65.462***	0.829***	0.001
	11.64	0.091	0.004
LD.Exchange rate (KSh/USD)	1378.133***	-0.277	0.417**
	395.193	3.1	0.144
Constant	-57.188	1.986	0.172
	808.832	6.346	0.294
R^2	0.421	0.619	0.149
N	58	58	58
Pass-through elasticity (global DAP)	0.56		
Pass-through elasticity (exchange rate)	1.55		
Mean dependent variable (in levels)	68072.41	577.50	76.61

Notes: *** sig at 1%, ** sig at 5%, * sig at 10%; all prices in nominal terms; "D" indicates difference, "LD" indicates lagged difference; entries are coefficients from VAR regression

Table C4. Maize price transmission within Kenya, ECM stage 1, 2007-2011

	Kisumu	Nairobi	Eldoret/Nakuru
Mombasa maize price (KSh/kg)	1.157	1.067	1.190
	0.048	0.048	0.060
Own petrol price (KSh/Lt)	0.032	-0.051	-0.110
	0.028	0.034	0.039
Nairobi DAP price (KSh/kg)	-0.043	-0.022	-0.050
	0.018	0.020	0.024
Constant	-1.134	6.221	8.325
	1.963	2.386	2.498
R^2	0.952	0.931	0.908
N	59	59	59

Notes: Entries are OLS coefficients

Table C5. Maize price transmission within Kenya, ECM stage 2, 2007-2011

	Kisumu	Eldoret/Nakuru	Nairobi
L.ECT^{neg}	-0.844**	-0.576**	-0.466*
	0.378	0.221	0.26
L.ECT^{pos}	-0.800***	-0.689***	-0.386*
	0.274	0.213	0.207
LD.POE maize price (KSh/kg)	-0.002	-0.228	0.245
	0.258	0.224	0.211
LD.Own maize price (KSh/kg)	0.433**	0.490***	0.114
	0.194	0.169	0.176
LD.Own petrol (KSh/Lt)	0.204	0.213	0.145
	0.162	0.128	0.119
LD.Nairobi DAP price (KSh/kg)	-0.041	0.007	-0.006
	0.05	0.05	0.04
R^2	0.39	0.36	0.35
N	57	57	57
F test: asymmetric (p-val)	0.916	0.684	0.793

Notes: *** sig at 1%, ** sig at 5%, * sig at 10%; all prices in nominal, local currency terms; ECT is the residual from a first stage regression of the sub-national market price on the POE price; "D" indicates difference, "LD" indicates lagged difference

Table C6. POE fuel and global fertilizer and oil, first-stage ECM results

	Ethiopia	Kenya	Tanzania	Uganda
Global oil ($/bl)	0.0516	0.580	6.001	12.95
	(0.00730)	(0.0280)	(0.770)	(1.061)
Global DAP ($/mt)	0.000137	0.00606	0.269	0.194
	(0.000710)	(0.00358)	(0.0647)	(0.115)
Exchange rate (Local/USD)	1.197	0.838	1.408	1.220
	(0.0433)	(0.0643)	(0.0737)	(0.0635)
Constant	-7.331	-25.36	-955.7	-962.8
	(0.329)	(4.668)	(68.47)	(107.7)
Observations	141	177	126	147
R-squared	0.955	0.944	0.965	0.938

Notes: dep. var. is the nominal POE petrol price; standard errors in parentheses; *** sig at 1%, ** sig at 5%, * sig at 10%;

Table C7. POE maize and global maize, fertilizer and oil, first-stage ECM results

	(1) Ethiopia	(2) Kenya	(3) Tanzania	(4) Uganda
Global maize ($/mt)	0.00468	0.026	0.539	1.15
	(-0.00295)	(-0.0154)	(-0.217)	(-0.505)
Global oil ($/bl)	0.0012	0.096	0.163	1.487
	(-0.00509)	(-0.0319)	(-0.562)	(-0.85)
Global DAP ($/mt)	0.00243	0.0000167	0.0286	0.0178
	(-0.000591)	(-0.00332)	(-0.0545)	(-0.101)
Exchange rate (Local/USD)	0.147	0.491	0.261	0.28
	(-0.0445)	(-0.079)	(-0.0527)	(-0.0712)
Constant	-1.047	-29.14	-155.3	-418.9
	(-0.242)	(-5.734)	(-39.65)	(-107.3)
N	144	143	144	135
R^2	0.752	0.604	0.693	0.682

Notes: dependent variable is the nominal POE maize price; standard errors in parentheses; *** sig at 1%, ** sig at 5%, * sig at 10%; global commodity prices are from the World Bank GEM database

Table C8. POE fuel and global fertilizer and oil, second-stage asymmetric ECM results

	Ethiopia	Kenya	Tanzania	Uganda
$L.ECT^{neg}$	-0.197***	-0.134***	-0.480***	-0.250***
	(0.0570)	(0.0391)	(0.103)	(0.0788)
$L.ECT^{pos}$	-0.121***	-0.112***	-0.0777	-0.215***
	(0.0418)	(0.0381)	(0.0885)	(0.0559)
D.Domestic CPI	0.0120	0.175***	-4.184	3.854
	(0.00812)	(0.0617)	(4.114)	(4.729)
LD.POE fuel (Local/L)	0.345***	0.168***	0.0268	0.180**
	(0.0713)	(0.0638)	(0.0874)	(0.0767)
LD.Global oil ($/bl)	0.00641	0.163***	1.427	-0.0997
	(0.00647)	(0.0279)	(1.040)	(1.518)
LD.Global DAP ($/mt)	0.000713	0.00621**	0.0209	-0.173
	(0.000644)	(0.00302)	(0.0965)	(0.161)
LD.Exchange rate (Local/USD)	0.158	0.327***	-0.0634	0.250*
	(0.137)	(0.0752)	(0.226)	(0.149)
LD.Domestic CPI	-0.000389	-0.0430	-1.179	-0.470
	(0.00849)	(0.0633)	(4.083)	(4.333)
N	139	145	121	145
R^2	0.512	0.656	0.308	0.249

Notes: dependent variable is the change in nominal POE maize price; standard errors in parentheses; *** sig at 1%, ** sig at 5%, * sig at 10%

Table C9. POE maize and global maize, fertilizer, and oil, second-stage asymmetric ECM results

	Ethiopia	Kenya	Tanzania	Uganda
L.ECT^{neg}	-0.0624	-0.0485	-0.0890*	-0.103
	(-0.0521)	(-0.0605)	(-0.0492)	(-0.0759)
L.ECT^{pos}	-0.193***	-0.184***	-0.135***	-0.174***
	(-0.0439)	(-0.0523)	(-0.051)	(-0.0584)
D.Domestic CPI	0.0342***	0.188**	3.835**	5.055
	(-0.00647)	(-0.08)	(-1.782)	(-3.346)
LD.POE maize (Local/kg)	0.155*	0.266***	0.410***	0.129
	(-0.0909)	(-0.0816)	(-0.11)	(-0.121)
LD2.POE maize (Local/kg)			-0.0883	0.138
			(-0.0899)	(-0.0936)
LD.Global maize ($/mt)	-0.00350*	0.0291*	-0.29	0.585
	(-0.002)	(-0.0155)	(-0.289)	(-0.708)
LD2.Global maize ($/mt)			0.073	0.0324
			(-0.207)	(-0.493)
LD.Global oil ($/bl)	0.0036	-0.0328	-0.363	-0.85
	(-0.00422)	(-0.0332)	(-0.589)	(-1.34)
LD2.Global oil ($/bl)			0.272	0.445
			(-0.47)	(-1.065)
LD.Global DAP ($/mt)	0.000246	-0.00196	-0.011	0.00842
	(-0.000471)	(-0.00356)	(-0.0543)	(-0.128)
LD2.Global DAP ($/mt)			0.0124	-0.227
			(-0.0587)	(-0.138)
LD.ER Local/USD	-0.0443	0.139	-0.041	-0.124
	(-0.0809)	(-0.111)	(-0.14)	(-0.123)
LD2.ER Local/USD			-0.0543	0.173
			(-0.116)	(-0.115)
LD.Domestic CPI	-0.00524	0.0393	-0.328	4.734
	(-0.00627)	(-0.084)	(-2.123)	(-3.727)
LD.2Domestic CPI			0.802	-7.164**
			(-1.85)	(-3.043)
N	142	141	141	132
R^2	0.47	0.228	0.267	0.27

Notes: dependent variable is the change in nominal POE maize price; standard errors in parentheses; *** sig at 1%, ** sig at 5%, * sig at 10%

Appendix D: Results of Johansen test for cointegration

In this Appendix section we report results for the cointegration tests that underlie all of the results in the main body of the paper. The tests are based on the method in Johansen (1991) and Johansen (1995). The full underlying specification is as follows:

$$\Delta x_t = \alpha(\mu + \beta x_{t-1} + \varphi t) + \sum_{i=1}^{s} [\gamma + \Gamma_i \Delta x_{t-i} + \psi t] + \varepsilon_t$$

where x is a vector including all of the variables in the analysis, the expression in standard parentheses is the "first-stage" or "long-run" equation, and the full expression is the second-stage equation. This is the single-stage analog to the two-stage error correction model that we use in the paper. For most of the tests in this section we impose $\varphi = \gamma = \psi = 0$, which eliminates the time trends and leaves a constant only in the long-run equation. The exception is the suite of tests for global oil and global maize prices (Table D1), which includes a variety of different sets of restrictions on the trend and constant structure. Additionally, for a small number of other specifications we altered the constant structure in accordance with the results of the tests and the requirement that the second-stage residuals approach white noise.

Table D1 shows the results from stage 1 of the analysis in the main body of the paper, which involves testing for cointegration between global oil prices and global maize prices. The 1% critical values corresponding to a maximum rank of 0 (no cointegration) are shown in the first column; columns 2 and 3 show the trace statistics for the full study period and for the period since the imposition of the US ethanol mandate in October 2006, respectively. In all cases the test statistic is less than the critical value, indicating a maximum of 0 cointegrating vectors.

In Table 2 we show results for specifications that include the price of oil on global markets, the exchange rate, and the POE fuel price in each country (estimated separately). Critical values for both 5% and 1% significance are provided. In all cases, the test indicates the presence of a single cointegrating vector at both 1% and 5% confidence.

Table D3 contains results for the global-POE maize equations, which also include the global oil price and the exchange rate. While the results are not as consistent across markets, in all cases the test indicates the presence of a single cointegrating vector at either 1% or 5% confidence.

In Table D4 we report results for the within-country fuel price equations, linking the POE fuel price to the price in the other sub-national markets (estimated separately). There are two cases in which the test actually fails to show cointegration: Kisumu, Kenya, and Gulu, Uganda. However, the test statistics are *very* close to the 5% significance threshold. In both cases it is highly likely that the series are cointegrated at the 6-7% level. All other markets show clear evidence of cointegration. Prices in Nairobi, Kenya are not cointegrated with the Mombasa (POE) prices unless a constant is included in the second-stage equation (in addition to the first-stage equation).

Finally, Table D5 shows results for the within-country maize equations, which include the local fuel price in addition to the POE maize and local maize prices. In most cases, results indicate a single cointegrating vector at both 1% and 5%. Maize prices in Bahir Dar, Ethiopia, are only cointegrated with Addis Ababa maize prices if a constant is included in the second-stage equation.

Table D1. Johansen test trace statistics, global oil prices and global maize prices

Specification	1% critical values for maximum rank of 0 (no cointegration)	Trace statistics Jan 2000 – Oct 2012	Oct 2006 – Oct 2012
Trend and constant in both equations	23.46	19.80	14.88
Constant in both, no trend in second stage	30.45	21.16	15.08
No trends, constant in both equations	20.04	10.33	12.52
Constant only in long-run equation	24.60	12.12	14.26
No trends or constants	16.31	10.54	8.55

Notes: entries are trace statistics from Johansen (1991) test of maximum rank; all specifications based on 2 lags (1 lag in differences), as indicated by BIC

Table D2. Johansen test trace statistics, global-POE fuel

Maximum rank	0	1	2
5% critical values	34.91	19.96	9.42
1% critical values	41.07	24.60	12.97
Trace statistics			
Addis Ababa, ET	45.65	14.57*^	4.40
Mombasa, KY	46.12	9.06*^	3.03
Dar es Salaam, TZ	51.70	17.87*^	7.73
Kampala, UG	54.48	14.10*^	4.94

Notes: entries are trace statistics from Johansen (1991) test of maximum rank; *sig at 5%; ^sig at 1%

Table D3. Johansen test trace statistics, global-POE maize

Maximum rank	0	1	2	3
5% critical values	53.12	34.91	19.96	9.42
1% critical values	60.16	41.07	24.60	12.97
Trace statistics				
Addis Ababa, ET	81.90	38.33^	20.47	7.34*
Mombasa, KY	57.56^	28.18*	10.94	3.41
Dar es Salaam, TZ[2]	57.25^	33.53*	17.77	7.54
Kampala, UG[2]	53.78^	28.78*	12.16	2.46

Notes: entries are trace statistics from Johansen (1991) test of maximum rank; *sig at 5%; ^sig at 1%; [2]indicates 2 lags (in differences); default is 1 lag in differences

Table D4. Johansen test trace statistics, within-country fuel price equations

Maximum rank		0	1
No constant in the second-stage equation			
5% critical values		19.96	9.42
1% critical values		24.60	12.97
Country	Market	Trace statistics	
Ethiopia	Bahir Dar[2]	23.11	4.32*^
	Dire Dawa[2]	27.06	3.87*^
	Mek'ele[2]	25.21	4.12*^
Kenya	Kisumu	18.48*^	3.24
	Eldoret/Nakuru	33.39	3.02*^
Tanzania	Arusha[2]	37.86	5.39*^
	Dodoma	38.40	5.27*^
	Kigoma[4]	27.15	5.16*^
	Mbeya	37.56	5.78*^
Uganda	Gulu	19.66*^	3.83
	Mbale	39.19	3.38*^
	Mbarara	24.04^	3.23*
Constant in the second stage equation			
5% critical values		15.41	3.76
1% critical values		20.04	6.65
Country	Market	Trace statistics	
Kenya	Nairobi	13.53*^	0.45

Notes: entries are trace statistics from Johansen (1991) test of maximum rank; *sig at 5%; ^sig at 1%; [2]indicates 2 lags (in differences); [3]indicates 3 lags; [4]indicates 4 lags; entries without a superscript are based on 1 lag

Table D5. Johansen test trace statistics, within-country maize price equations

Maximum rank		0	1	2
No constant in the second-stage equation				
5% critical values		34.91	19.96	9.42
1% critical values		41.07	24.60	12.97
Country	Market	Trace statistics		
Ethiopia	Dire Dawa	56.73	13.77*^	3.28
	Mek'ele[3]	35.22^	8.90*	3.85
Kenya	Kisumu	57.54	15.64*^	5.05
	Nairobi	42.10	13.27*^	3.24
	Eldoret/Nakuru	46.43	16.66*^	4.68
Tanzania	Arusha	51.41	18.09*^	6.40
	Dodoma	43.98	22.14^	5.32*
	Kigoma[2]	42.93	16.69*^	8.14
	Mbeya	53.81	20.34^	6.54*
Uganda	Gulu	36.66^	16.70*	6.35
	Mbale	35.90^	15.54*	2.73
	Mbarara	38.52^	14.43*	3.34
Constant in the second stage equation				
5% critical values		29.68	15.41	3.76
1% critical values		35.65	20.04	6.65
Country	Market	Trace statistics		
Ethiopia	Bahir Dar[2]	35.53^	11.29*	1.09

Notes: entries are trace statistics from Johansen (1991) test of maximum rank; *sig at 5%; ^sig at 1%; [2]indicates 2 lags (in differences); [3]indicates 3 lags