Global Oil Prices and Local Food Prices: Evidence from East Africa

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

April 2014

Abstract:

It is widely believed that oil prices impact food prices in developing countries. Yet evidence on this relationship is scarce. Using maize and petrol price data from east Africa we show that global oil prices do affect food prices, but primarily through transport costs, rather than through biofuel or production cost channels. For inland markets, world oil prices have larger effects on local maize prices than do world maize prices. Furthermore, oil price shocks transmit much more rapidly than maize price shocks, suggesting that policies to assist food insecure households during correlated commodity price spikes should consider transport cost effects.

Keywords: African development; agricultural markets; energy markets; food price volatility; price transmission
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

[*] We thank Joanna Barrett and Shun Chonabayashi for research assistance, Chris Adam, Heather Anderson, Channing Arndt, John Baffes, Anindya Banerjee, Marc Bellemare, Harry de Gorter, Oliver Gao, Doug Gollin, Miguel Gómez, Yossie Hollander, Wenjing Hu, David Lee, Matt Nimmo-Greenwood, Per Pinstrup-Andersen, Tanvi Rao, Stephan von Cramon-Taubadel, seminar participants at the IATRC 2013 and CSAE 2014 annual meetings, the IMF/OCP/NYU 2014 conference on food price volatility, and seminar audiences at Cornell, Melbourne, Monash, Sydney, and Wisconsin for helpful comments on earlier drafts, and the Bill and Melinda Gates Foundation for financial support. We thank Todd Benson, Pasquel Gichohi, Bart Minten, Mujo Moyo, Temesgen Mulugeta, Andrew Mutyaba, Guush Tesfay and Bjorn Van Campenhout for help assembling the data. This project was partly undertaken through a collaborative arrangement with the Tanzania office of the International Growth Center. Barrett thanks the Australian-American Fulbright Commission, Monash University and U. of Melbourne for hospitality, and Dillon thanks the Harvard Kennedy School for support through the Sustainability Science program. Any remaining errors are the responsibility of the authors.

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 ongoing debate over the causes of these price spikes, one prominent thread emphasizes the role of oil prices (Abbott et al. 2008, Headey and Fan 2008, Krugman 2008, Mitchell 2008, Rosegrant et al. 2008, Baffes and Dennis 2013, Wright 2014). Yet there is a notable absence of careful empirical analysis of the links between global oil markets and the food prices that most affect the poor, i.e., those in markets within developing countries. How and by how much do global crude oil price shocks affect local food prices, particularly in countries with high levels of subsistence food production?

This paper tackles that important question, focusing on maize markets in the four major east African economies: Ethiopia, Kenya, Tanzania and Uganda. These markets are ideal for studying the oil-food link in developing economies. Maize is the primary staple food in east Africa, serving as the greatest source of calories for consumers and the largest source of income for farmers. Maize is also the main input to global biofuels production due to the reliance of the US ethanol industry on corn (maize) as a feedstock. Furthermore, east Africa is distant from major maize exporters and burdened with poor transport infrastructure, so that transport fuel costs are potentially significant.

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 commonly made from natural gas, and fuel for tractors or pumps. Second, higher global oil prices can stimulate market demand for corn to convert into biofuel, thereby driving up maize prices on the global market, which then transmit to local markets through trade linkages. Third, oil price increases can drive up transport costs, which affect the prices of all traded commodities, food grains included.

Theory suggests that the production cost channel should be a second-order concern for the study countries, all of which are integrated with world maize markets and act as pure price-takers for maize. For these economies, changes in production costs may affect profits and output levels, and may influence short-run prices in remote markets. But local production costs should not drive long-run equilibrium prices. This is indeed what we find. Once we control for changes in global maize prices, which capture the direct effects of global oil price shocks on production costs in the world's major maize producing countries, we find a negligible role for fertilizer prices in local maize price determination.[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 mandate in the US Energy Policy Act of 2005 (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 (Appendix B). We therefore do not emphasize this channel. However, in interpreting results we 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 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 lorries. Although subsistence food production is still widespread, 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

[1] See Appendix A for more details. Only a tiny fraction of the maize grown in east Africa is produced using tractors or irrigation pumps. Kenya is the only country with widespread fertilizer application during the study period. In the appendix we show that maize prices in Kenya are not responsive to changes in the price of fertilizer. We also show that after controlling for the global prices of maize and oil, global fertilizer prices are not an important determinant of domestic prices of maize or fuel in any of the study countries.

changes on petrol and maize prices in the port-of-entry (POE) markets for the four study countries. 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), we allow for asymmetric adjustment to price increases and decreases in all steps.

This empirical strategy rests on four key identifying assumptions, discussed in detail in Section 3. Three are rather innocuous: first, that study countries are price takers on global markets; second, 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 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 C we show 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; 15 of the 17 estimated global-to-local oil price pass-through rates lies in the range 0.10-0.41%. In comparison, the average elasticity of the local maize price with respect to global maize price is 0.42, 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. 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 markets that are farthest from an ocean port, 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 general, the estimated elasticity of local maize to global oil is increasing in distance from the domestic port-of-entry. For landlocked areas, variable transport costs have a large and often overlooked effect on food prices, and therefore on food security.

Third, we find that oil price shocks transmit rapidly to the pump and then to local maize prices, much more rapidly 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 international 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* policies to mitigate food price shocks, such as export bans or releases of grain 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 more to changes in transport costs than to changes in the global prices of grains. To the extent that governments ignore the fuel channel and typically attempt to mitigate food price spikes by intervening exclusively in grain markets, policy responses may not achieve the desired price stabilization effects.

These findings contribute to a number of strands in the literature. There is a large body of economic research 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] To our knowledge this is the first paper to make use of variable transport costs in a study of food price determination in the developing world. The lack of rigorous research on this topic is likely due to the scant availability of spatially disaggregated data on variable transport costs (World Bank, 2009, p. 175), which we assembled from a wide range of sources.

More broadly, our findings add to the large literature on food security, vulnerability to shocks, and economics outcomes for rural households in poor countries (Baulch and Hoddinott 2000, Dercon 2002, Barrett et al. 2006, Jack and Suri 2014). While there is substantial work on the impacts of covariate (e.g., weather) and idiosyncratic (e.g., health) shocks on food production and welfare, much less is known about the link between

[2] See Storeygard (2012) for a recent study in Africa that incorporates both fixed and variable transport costs.

price changes in non-food commodity markets and local food prices. It is striking that long run equilibrium maize prices in the most inland markets in our study are influenced more by global oil prices than by global maize prices or local conditions. Because poor households in sub-Saharan Africa, even in agricultural areas, are overwhelmingly net food buyers (Barrett 2008, Ivanic et al. 2012), this finding suggests that rising oil prices represent a much more significant threat to welfare than has been previously documented in the literature.

This paper also speaks to broader 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 the existing literature often struggles to identify the source(s) of frictions that lead to incomplete, slow, or asymmetric price pass-through, for example in financial markets (Constantinides 1986, Michael et al. 1997), here the frictions arise naturally from observed 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, this paper connects to the literature on commodity price dynamics and global-to-local price transmission, especially in Africa (Ardeni and Wright 1992, Deaton and Laroque 1992, 1996, Deaton 1999, Sacks et al. 2011). As Deaton 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" (1999, p. 24). 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.

2. Data and Setting

Background: Maize in east Africa

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.

Table 1 shows the allocation of land to maize and other crops over the period 2007-2010. In all four countries the land area of maize cultivation is greater than that of any other single crop.[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 acreage and output show upward trends over the study period. In Tanzania there is 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 statistics for 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 inter-temporal variation. 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, governments in the four study countries have largely withdrawn from direct participation in the production, distribution, or pricing of food and fuel. The primary 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 occasional *ad hoc* export bans, are discussed in Appendix D.

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. The port-of-entry (POE) markets are Mombasa, Kenya; Dar es Salaam, Tanzania; Kampala, Uganda; and Addis Ababa, Ethiopia. We focus on the period 2000-2012, with slight variation in the coverage period due to data limitations.

---

[3] See FAOstat for exact details by crop.

[4] While the FAO data are the best available, the output and acreage numbers should be read with caution. Measurement error is a substantial concern (Jerven 2013).

We use monthly average prices for all data series because higher frequency data were not available. Global prices are from the World Bank GEM database. Crude oil prices (nominal $/barrel) are the average spot prices for major world markets. Maize prices are nominal $/metric ton for number 2 yellow maize in the US Gulf. In Figure 5 we plot the global prices. The series co-move somewhat, though there is no obvious causal relationship. The correlation coefficient between the nominal price series is 0.83. After deflating to 2005 prices using the world CPI from the IMF, the correlation coefficient is 0.45.

Wholesale maize prices for Kenya are from the Ministry of Agriculture, via the International Growth Center (IGC). Wholesale maize prices for Ethiopia are from the Ethiopia Grain Trade Enterprise (EGTE). Retail 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] When needed, we use the monthly CPI and USD exchange rates for each country, from the IMF.

In Figure 6 we plot the POE maize prices against global maize prices.[6] For ease of comparison, global prices are expressed in local, nominal units. While intra-annual seasonality related to the harvest cycle is clearly visible, the long-run trajectories of prices in each market track the shifts in global prices.

For sub-national 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. The national bureaus of statistics in

---

[5] To accommodate missing values in the Uganda RATIN series, we predict prices using least squares estimates based on regressions of RATIN prices on Uganda maize prices from non-study markets that are available from other sources, such as FEWS, Uganda FoodNet, and the FAO. Details available upon request. We use a similar procedure to replace a small number of missing prices in the other countries.

[6] Farmers in study countries typically grow white maize, but we have global prices for yellow maize. We believe this to be of little consequence, as the prices are highly correlated.

[7] Petrol and diesel prices are highly correlated in those markets for which we have both.

Kenya and Uganda provided their respective monthly average retail prices of petrol.[8] For Tanzania, pump prices were provided by the Bank of Tanzania and IGC.

Figure 7 shows the time path of POE fuel prices plotted 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 the top left panel.

Additional descriptive details for the price data are provided in Appendix D.

3. Empirical Approach

All of the price data in this paper are nonstationary I(1) series.[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 8 summarizes the approach. We begin by estimating the relationship between the global prices of oil and maize (step 1). In step 2 we 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. 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-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 local fuel prices to impact the maize price spread (step 4). In all steps we allow for possible asymmetric adjustment to negative/positive deviations from long run equilibrium.

This approach rests on four key identifying assumptions:

---

[8] In Kenya, we could assemble fuel price data from Nakuru but not from Eldoret, and vice versa for maize. These cities are proximate, and are the two main urban areas of Rift Valley Province in Kenya. We merge them into a synthetic series, using Eldoret maize prices and Nakuru fuel prices.

[9] Results available upon request.

Assumption 1. *Each country is a price taker on global markets for both maize and oil*. This is an innocuous assumption for the study countries.

Assumption 2. *There is no feedback from maize prices to fuel prices within study countries, rendering petrol prices weakly exogenous to maize prices.* 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 (Table 2). 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. Also, in Appendix C we show that in the symmetric version of our model, 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 interpreting results, we accommodate this by separately assuming zero and complete exchange rate adjustment to changes in commodity prices, which gives bounds on cumulative pass-through elasticities.

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.[10] Estimating the entire system simultaneously would make it much more difficult to interpret the cointegrating vectors, and would require that we mis-specify the short run equations by imposing symmetry.[11]

Step 1. Global Oil - Global Maize Price Linkages

Rank tests indicate that global oil and global maize prices are not cointegrated. This is consistent with numerous other recent papers that find no strong causal link between oil prices and maize prices at world markets (Zhang et al. 2007, 2009, 2010, Gilbert 2010, Serra et al. 2011, Enders and Holt 2012, Zilberman et al. 2013). Although it remains possible, even likely, that a causal relationship exists between these market prices (de Gorter et al. 2013), we proceed under the assumption that the global oil price does not directly impact the global maize prices. This is a conservative approach: if there is a causal relationship from global oil to global maize, our estimates are lower bounds on the true impact of oil prices on maize prices in Africa. However, because we do not emphasize this channel, we relegate the empirical details and the results of step 1 to Appendix B.

Step 2. Global-POE Price Linkages

For all four countries, rank tests based on Johansen (1991, 1995) indicate a single cointegrating vector between global oil prices, POE fuel prices, and the exchange rate, with a constant in the long-run equation (Appendix E). 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): [12]

---

[10] For multiple reasons, we do not 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) occurred near the start or end of the study period. Second, there are few clear, discrete policy changes that can be confidently assigned to specific months. Third, many relevant policies are endogenous to market conditions; for example, export bans are a direct response to higher prices.

[11] We are not aware of any papers that estimate a vector error correction model as a single system while allowing for asymmetry in the short-run equations. Developing this here would take us well beyond the scope of this paper.

[12] Out of concern for overfitting, we do not allow for thresholds in the error correction mechanism.

(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 (Engel 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, denoted 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.[13] 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, $ECT_t \equiv F_{t-1}^{POE} - \hat{\alpha} - \hat{\beta}_1 F_{t-1}^G - \hat{\beta}_2 ER_{t-1}$, 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}). Estimates $\hat{\delta}_0$ and $\hat{\delta}_1$ are 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 $|\hat{\delta}_0|$ and $|\hat{\delta}_1|$ give the share of the deviation from long-run equilibrium that decays each month.

[13] While a log-log specification may be more familiar to readers as a way to estimate elasticities, we prefer the specification in levels so that we can interpret coefficients in terms of price spreads rather than proportions. This is innocuous: log-log specifications give similar elasticity estimates.

There are various reasons to expect asymmetries in adjustment to long-run equilibrium. The relationships in equations 1 and 2 reflect both spatial price transmission and transformation of crude oil inputs into refined fuel. 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 above. Rank tests show that the series in equations 3 and 4 are cointegrated (Appendix E).

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. Domestic prices are linked to global price movements through near-constant cross-border trade, but policymakers have supply-side tools to stabilize maize prices that are not available for fuel prices (e.g., export bans, input subsidy programs). Indeed ne thread of the literature on the 2008-2011 global food price shocks emphasizes the extent to which national governments used policy instruments to buffer their constituents against price movements (Baltzer 2013). Also, households that grow maize often store grain for months after the harvest, as a savings device and a hedge against food price shocks. Nonetheless, in almost all periods the return to transporting maize from the breadbasket region(s) to any other market is constrained by the available return from transporting the crop to the port for export. Global maize prices are thereby transmitted to domestic maize prices through port-of-entry prices.

Step 3. Within-country fuel price transmission

We expect fuel prices in sub-national markets other than the POE to reflect POE fuel 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 SBC indicates an optimal lag length of two months in levels (1 month in differences). Accordingly, for each POE/other market pair, we estimate the following ECM:

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

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

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. Within-country maize price transmission

The final relationships of interest are those between POE maize prices and maize prices at sub-national markets. Here, we allow local fuel prices to affect maize price spreads between the POE and other markets. Once again, 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:

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

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

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, to allow for the asymmetric structure. In some cases, after initial estimation we added lags to the second-stage equations to ensure white noise residuals (Enders 2010).

4. Results

Global-POE price transmission

Table 3 shows the estimates of equation 1, for all four countries. POE retail fuel prices are increasing in both global oil prices and the exchange rate, as expected. Because the error term is nonstationary, we do not provide stars indicating statistical significance. The key findings in Table 3 are summarized in the average pass-through elasticities for oil price changes and exchange rate changes, in the bottom panel. 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 4 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 fast on average, with monthly adjustment rates ranging from 14-56%. Price increases generally transmit faster than price decreases, though only in Tanzania is the difference between positive and negative adjustment statistically significant. This is consistent with 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.

Table 5 shows estimates of equation 3, the cointegrating vectors linking global and POE maize prices. 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. This is consistent with between-country variation in the degree of government intervention in maize markets. Relative to its neighbors, Kenya's activist tariff and marketing board policies dampen transmission of global maize prices to the national market. 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.

To show the seasonality in the deviations from long-run equilibrium, we plot monthly average residuals from estimates of equation 3 in Figure 9, normalized by the average POE maize price. The seasonal patterns evident in the series coincide with intra-annual fluctuations in 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. This serves as a helpful check that local production generates merely short-run deviations from long-run equilibrium prices set through global trade relationships.

Second stage ECM results for the global-to-POE maize price relationship, based on equation 4, are shown in Table 6. The error correction terms are highly significant during periods of positive deviation from long-run equilibrium (ECT^{pos}), the opposite of what we found for POE fuel prices. One interpretation 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. Above equilibrium POE maize prices are generally absorbed in no more than 6-8 months, with the arrival of the next harvest. Below equilibrium prices (ECT^{neg}) persist far longer. However, only in Ethiopia is the asymmetry significant at 5%. Coefficient estimates on lagged differences in global oil prices are not significant in any of the equations, suggesting that at the global-POE level, changes in transport costs matter more for the long-run equilibrium (Table 5) than for short-run price dynamics.

Within-country petrol price transmission

Table 7 shows the estimates of equation 5, linking fuel prices in sub-national markets to the POE fuel price. 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 8. 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. Kenya adjustment rates are slower on average, though still rapid.

Within-country maize price transmission

Table 9 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 Ethiopia markets, Arusha, Dodoma, and Eldoret/Nakuru are all less than 0.06 in absolute magnitude. The outlier in Table 9 is the -0.618 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 10 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.

In Table 10 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 9) than in mediating adjustments to those equilibria (Table 10).

5. Discussion

To estimate the full impact of a global oil price increase on equilibrium maize prices in east Africa, we combine the estimated cointegrating vectors and short-run adjustment results across price series pairs. Table 11 summarizes the speed-of-adjustment findings by showing the number of months needed to absorb 80% of a price increase. In all four POE markets, it takes substantially longer to return to maize price equilibrium after a global maize price rise than it does to return to petrol price equilibrium following a global oil price rise (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 two rightmost columns in Table 11, which show the sums of columns 3 and 4, and of columns 1, 2, and 4, respectively, show the cumulative speeds of adjustment.[14] These estimates account for both border effects and within country price dispersion. In all cases, maize prices converge to new equilibria 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, the magnitude of the difference is striking. The implication is that in the face of correlated increases in global maize and oil prices, short term impacts on food prices in east Africa are driven more by transport costs than by the direct pass-through effects of higher grain prices.

Of course, rapid pass-through from oil prices to food prices matters only if the total impact is of significant magnitude. In Table 12 we see that it is. The table shows 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 previous tables. Entries are the products of elasticity estimates from steps in the chain of price transmission.

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

[14] 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.

in Tanzania, and 0.23-0.53 in Uganda. Dampening of maize-to-maize price transmission primarily occurs across international frontiers (Table 5). We have already seen that within each country, long-run spatial equilibrium in maize prices corresponds to the law of one price, consistent with a longstanding literature (Engel and Rogers 1996, Evans 2003, Anderson and van Wincoop 2004).

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, which is indicative of the role of macroeconomic adjustment to terms of trade shocks in determining equilibrium prices. In fact, these cross-country differences likely reflect differences in the importance of maize in the general price indices, which then affects the exchange rate. Maize is most critical to consumption in Kenya and that is where we see the strongest links between exchange rates and maize prices.

The key findings in Table 12 are the cumulative impacts of global oil price changes on local maize prices (column 2). In the Kenya markets, as well as in the more remote markets of Gulu and Mbarara, in Uganda, and Kigoma, Tanzania, the elasticity of local maize to global oil price is greater than the elasticity of local maize to global maize. 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 (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 global oil price elasticities are approximately half the magnitude of global maize price elasticities. Across the sample, the average global maize price elasticity is 0.42, while the average global oil price elasticity is 0.26. These global oil price elasticities assume no link between oil and maize prices on global markets. If such links exist, the average elasticity of local maize prices to global oil prices is greater than 0.26. This underscores the importance of variable transport costs in determining equilibrium food prices in Africa.

Putting these results together, what do we expect to happen in African maize markets when global commodity prices move? Table 13 shows the full impact on local maize prices from four price change scenarios. Scenarios 1 and 2 correspond to 1% increases in the global prices of oil and maize, respectively. These summarize our above findings. The third scenario considers simultaneous 1% price rises for both crude oil and maize, while assuming no impact on the exchange rate. Scenario 4 incorporates possible macroeconomic impacts on exchange rates by assuming that global oil prices, global maize prices, and exchange rates all increase by 1%. Scenarios 3 and 4, therefore, provide bounds on the total effect allowing for zero and complete exchange rate adjustment, respectively. Because commodity prices regularly co-move due to common underlying macroeconomic drivers, we consider these two scenarios to be the most realistic (Byrne et al. 2013).

Aggregate pass-through rates in scenario 3 are reasonably high: over 100% pass-through in Ethiopia, 52-63% in Kenya, 43-47% in Tanzania, and 56-70% in Uganda. These changes occur in the absence of exchange rate adjustment. When we allow the exchange rate to depreciate by 1% (scenario 4), all of the cumulative local maize price elasticities are greater than unity. In most Ugandan markets the estimated elasticity approaches 2; in Kenya, estimates lie in the range 2.61-3.06. These are upper bounds on true pass-through elasticities, because they are premised on an out-of-equilibrium exchange rate change.[15] However, the disparity in the relative importance of exchange rate changes across the study countries is noteworthy. 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.

6. Conclusions

The potential for global oil price shocks to disrupt food markets in developing countries is of serious concern to policymakers and practitioners. In this paper we systematically examine the global oil – local food price link in east African maize markets. 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. We estimate 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 transport fuel prices to influence maize price spreads as a way to capture the effects of variable transport costs. We also provide evidence that some of the mechanisms thought to link oil prices to maize prices in the United States – ethanol markets, fertilizer prices, or the price of fuel for production equipment – matter little in east Africa, where transport costs are the primary channel linking oil to food.

[15] See Adam (2011) for a macroeconomic model of food prices shocks with endogenous exchange rate adjustment.

We find that both global oil and global maize prices exert considerable influence on sub-national maize prices across east Africa. Cross-border price transmission is less complete than that within countries, with the latter largely following the law of one price in long-run equilibrium for both fuel and maize. Yet our most conservative estimates still suggest an average pass-through elasticity from global oil to local maize of 0.26. More realistic estimates, allowing for correlated oil and maize price movements at global markets, approach or exceed one.

Oil price shocks also transmit quickly to local maize prices, with adjustments to the new equilibrium typically taking place within a few months. The transmission from global maize to local maize is considerably slower, likely owing to localized supply responses as well as policy interventions and infrastructural bottlenecks that impede trade. Oil price impacts necessarily vary with overland travel distance. 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. The implication is that for more remote regions, policymakers concerned about the impacts of food prices on poverty and food security should pay at least as much attention to global oil markets and their effects on transport costs as they do to the cereals markets that have historically been the center of policy attention.

These findings have other important policy implications. For price-taking economies, and especially 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 food security objectives. Increased high-level attention to global food security tends to focus on farm productivity growth and on safety nets for consumers. Although these are clearly high priorities, it is also essential to increase efficiency in the post-harvest systems – including transport – that deliver food to rapidly urbanizing populations from both domestic farmers and international markets (Gómez et al. 2011).

References

Abbott, P. C., C. Hurt, W.E. Tyner (2008). *What's Driving Food Prices?* Oak Brook, IL: Farm Foundation.

Abbott, P, A Borot de Battisti (2011). "Recent Global Food Price Shocks: Causes, Consequences and Lessons for African Governments and Donors", *Journal of African Economies* 20(s1): i12-i62.

Adam, C (2011). "On the Macroeconomic Management of Food Prices Shocks in Low Income Countries", *Journal of African Economies* 20: 63-99.

Anderson, J.E., E van Wincoop (2004). Trade Costs. *Journal of Economic Literature* 42(3): 691–751.

Ardeni, P.G., B.D. Wright (1992) "The Prebisch-Singer Hypothesis: A Reappraisal Independent of Stationarity Hypotheses." *Economic Journal* 102: 803-12.

Ariga, J and TS Jayne (2009). "Private Sector Responses to Public Investments and Policy Reforms: The Case of Fertilizer and Maize Market Development in Kenya", IFPRI Discussion Paper #00921.

Baffes, J. and A. Dennis (2013). "Long-Term Drivers of Food Prices," World Bank Policy Research Working Paper 6455.

Baltzer, K. (2013). "International to domestic price transmission in fourteen developing countries during the 2007-08 food crisis", UN WIDER Working Paper 2013/031.

Barrett, C.B., S.M. Sherlund, A. Adesina (2006). "Macroeconomic Shocks, Human Capital and Productive Efficiency: Evidence from West African Rice Farmers." *Journal of African Economies* 15(3): 343-372.

Barrett, C.B. (2008). "Smallholder Market Participation: Concepts and Evidence from Eastern and Southern Africa," *Food Policy* 33(4): 299-317.

Barrett, C.B., ed. (2013). *Food Security and Sociopolitical Stability*. Oxford: Oxford University Press.

Baulch, B. and J. Hoddinott (2000). "Economic Mobility and Poverty Dynamics in Developing Countries." *Journal of Development Studies* 36(6): 1-24.

Benson, T., S. Mugarura, K. Wanda (2008). “Impacts in Uganda of rising global food prices: The role of diversified staples and limited price transmission”, *Agricultural Economics* 39(S1): 513–524.

Borenstein, S., A.C. Cameron and R. Gilbert (1997). “Do Gasoline Prices Respond Asymmetrically to Crude Oil Price Changes?” *Quarterly Journal of Economics* 112(1): 305-339.

Byrne, J.P., G. Fazio, and N. Fiess (2013). “Primary commodity prices: Co-movements, common factors and fundamentals”, *Journal of Development Economics* 101(1): 16-26.

Constantinides, G.M. (1986). “Capital Market Equilibrium With Transaction Costs.” *Journal of Political Economy* 94(4): 842-862.

Deaton, A (1999). “Commodity prices and growth in Africa,” *Journal of Economic Perspectives* 14(3): 23-40.

Deaton, A, G Laroque (1992). "On the behavior of Commodity Prices." *Review of Economic Studies* 59(1): 1-24.

Deaton, A, G Laroque (1996). "Competitive Storage and Commodity Price Dynamics." *Journal of Political Economy* 104(5): 896-923.

de Gorter, H., D. Drabik, D.R. Just and E.M. Kliauga (2013). “The impact of OECD biofuels policies on developing countries.” *Agricultural Economics* 44(4): 477-486.

Dercon, S (2002). “Income Risk, Coping Strategies, and Safety Nets.” *World Bank Research Observer* 17(2): 141-166.

Enders, W (2010). *Applied Econometric Time Series, Third Edition.* New York: Wiley.

Enders, W. and M. Holt (2012). “Sharp Breaks or Smooth Shifts? An Investigation On The Evolution of Primary Commodity Prices,” *American Journal of Agricultural Economics* 94(3): 659-673.

Engel C,. J.H. Rogers (1996). How Wide is the Border? *American Economic Review* 86(5): 1112-1125.

Engle, R.F. and C. Granger (1987). Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica* 55(2): 251-276.

Evans C. (2003). The Economic Significance of National Border Effects. *American Economic Review* 93(4): 1291-1312.

Gilbert, C.L. (2010). "How to understand high food prices", *Journal of Agricultural Economics* 61(2): 398–425.

Gómez, M.I., C. B. Barrett, L. E. Buck, H. De Groote, S. Ferris, H. O. Gao, E. McCullough, D. D. Miller,H. Outhred, A. N. Pell, T. Reardon, M. Retnanestri, R. Ruben, P. Struebi, J. Swinnen, M. A. Touesnard, K. Weinberger, J. D. H. Keatinge, M. B. Milstein, R. Y. Yang (2011). "Food Value Chains, Sustainability Indicators and Poverty Alleviation", *Science* 332(6034): 1154-1155.

Headey, D., S. Fan (2008). Anatomy of a crisis: The causes and consequences of surging food prices, *Agricultural Economics 39*(3):375–391.

Ivanic, M., W. Martin, H. Zaman (2012). Estimating the short-run poverty impacts of the 2010–11 surge in food prices. *World Development* 40(11): 2302–17.

Jack, W and T Suri (2014). "Risk Sharing and Transaction Costs: Evidence from Kenya's Mobile Money Revolution", *American Economic Review* 104(1): 183-223.

Jayne, T.S., R.J. Myers, J. Nyoro (2008). "The effects of NCPB marketing policies on maize market prices in Kenya", *Agricultural Economics* 38(3): 313–325.

Jerven, M (2013). *Poor Numbers: How We Are Misled by African Development Statistics and What to Do about It.* New York: Cornell University Press.

Johansen, S (1991). "Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models", *Econometrica* 59(6): 1551-1580.

Johansen, S (1995). *Likelihood-based Inference in Cointegrated Vector Autoregressive Models*. Oxford: Oxford University Press.

Kojima, M, W Matthews, F Sexsmith (2010). "Petroleum Markets in Sub-Saharan Africa", World Bank Extractive Industries for Development Series #15.

Krugman, P. (2008). “Running out of planet to exploit”, *New York Times* April 21.

Meyer, J., S. von Cramon-Taubadel (2004) “Asymmetric price transmission: a survey”, *Journal of Agricultural Economics* 55(3): 581-611.

Michael, P., A. R. Nobay, and D.A. Peel (1997), “Transactions Costs and Nonlinear Adjustment in Real Exchange Rates: An Empirical Investigation.” *Journal of Political Economy* 105(4): 862-879.

Mitchell, D. (2008). “A Note on Rising Food Prices”, World Bank Policy Research Working Paper #4682.

Peltzman, S. (2000). “Price rise faster than they fall.” *Journal of Political Economy* 108(3): 466-502.

Pinstrup-Andersen, P, ed. (2013). *Food Price Policy in an Era of Market Instability: A Political Economy Analysis*. Oxford University Press, forthcoming.

Rashid,S., K. Getnet, S. Lemma (2010). Maize value chain potential in Ethiopia: Constraints and opportunities for enhancing the system. International Food Policy Research Institute working paper.

Rosegrant, M. W., T. Zhu, S. Msangi, T. Sulser (2008). “Global scenarios for biofuels: Impacts and implications”, *Review of Agricultural Economics* 30(3): 495–505.

Sacks, D, K O’Rourke, and J Williamson (2011). “Commodity Price Volatility and World Market Integration since 1700”, *Review of Economics and Statistics* 93(3): 800-813.

Serra, T., D. Zilberman, J. Gil, B.K. Goodwin (2011). “Nonlinearities in the U.S. corn-ethanol-oil-gasoline price system”, *Agricultural Economics* 42(1): 35-45.

Spielman, D, D Kelemwork, D Alemu (2011). “Seed, Fertilizer, and Agricultural Extension in Ethiopia”, IFPRI ESSP II Working Paper 20.

Storeygard, A (2012). “Farther on down the road: transport costs, trade, and urban growth in sub-Saharan Africa”, Tufts University working paper.

van Campenhout, B. (2007). "Modelling trends in food market integration: Method and an application to Tanzanian maize markets", *Food Policy* 32(1): 112-127.

World Bank (2009). *World Development Report 2009: Reshaping Economic Geography*.

Wright, B (2014). "Global Biofuels: Key to the Puzzle of Grain Market Behavior", *Journal of Economic Perspectives* 28(1): 73-98.

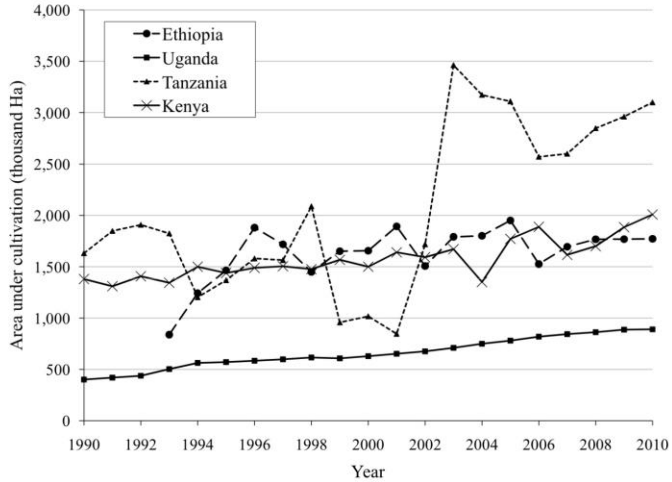
Zhang, Z., D. Vedenov, M. Wetzstein (2007). **"**Can the U.S. ethanol industry compete in the alternative fuels market?" *Agricultural Economics* 37(1): 105–112.

Zhang, Z., L. Lohr, C. Escalanate, M. Wetzstein (2009). "Ethanol, Corn, and Soybean Price Relations in a Volatile Vehicle Fuels Market", *Energies* 2(2): 320-339.

Zhang, Z., L. Lohr, C. Escalanate, M.Wetzstein (2010). "Food versus fuel: What do prices tell us?" *Energy Policy* 38 (1): 445–451.

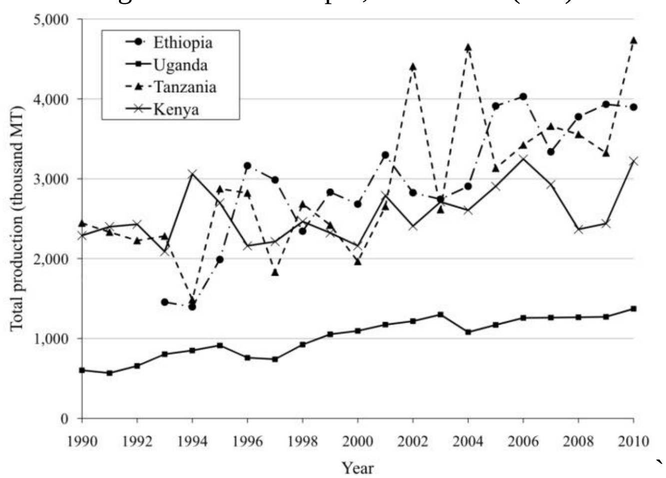
Zilberman, D., G. Hochman, D. Rajagopal, S. Sexton, G. Timilsina (2013). "The Impact of Biofuels on Commodity Food Prices: Assessment of Findings", *American Journal of Agricultural Economics* 95(2): 275-281.

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



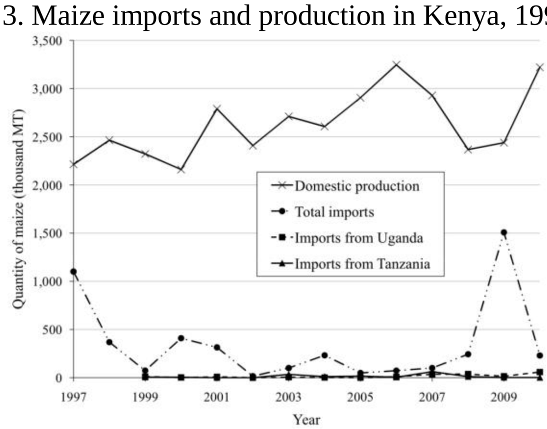
Data source: FAOStat

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)

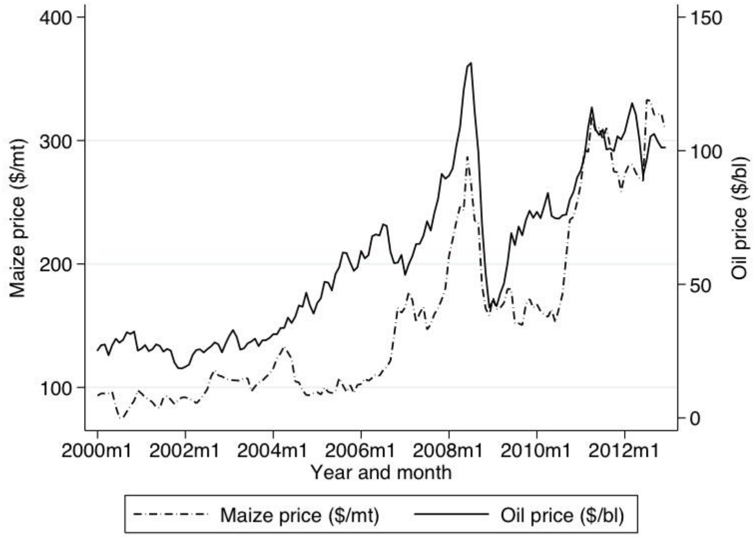


Figure 6. Global maize prices and maize prices in the POE markets, 2000-2012

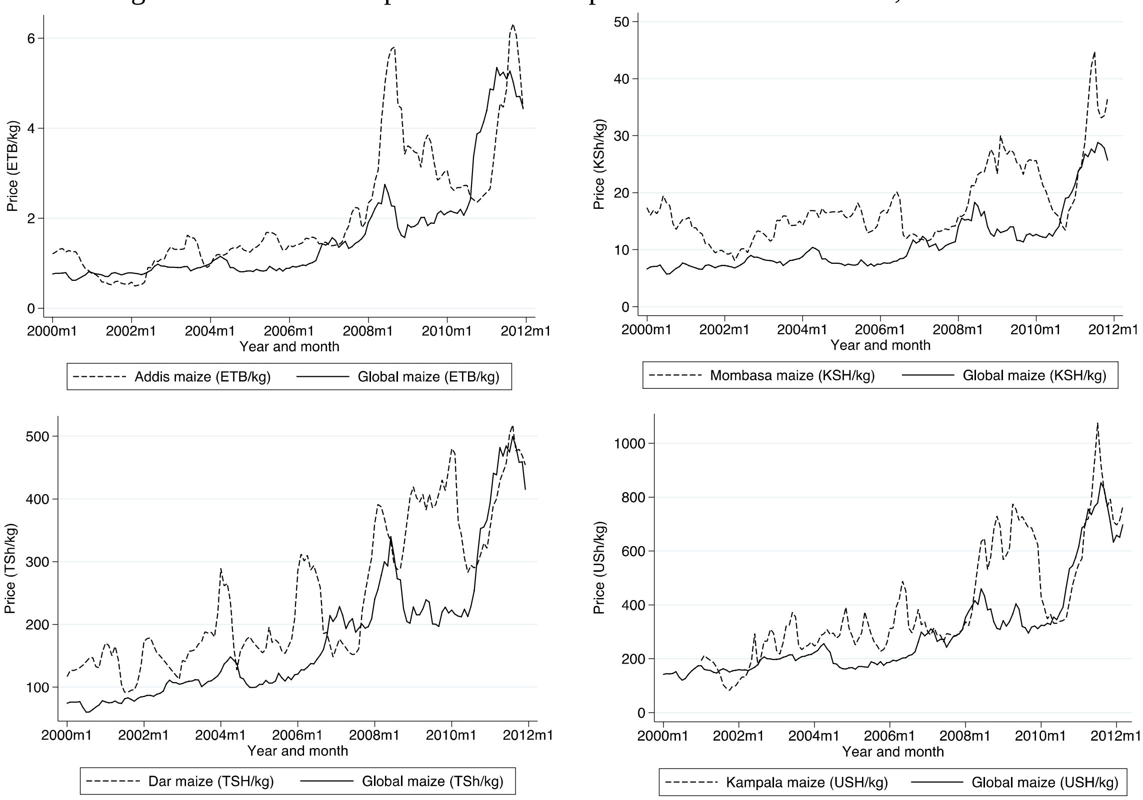


Figure 7. Global oil prices and petrol prices in the POE markets, 2000-2012

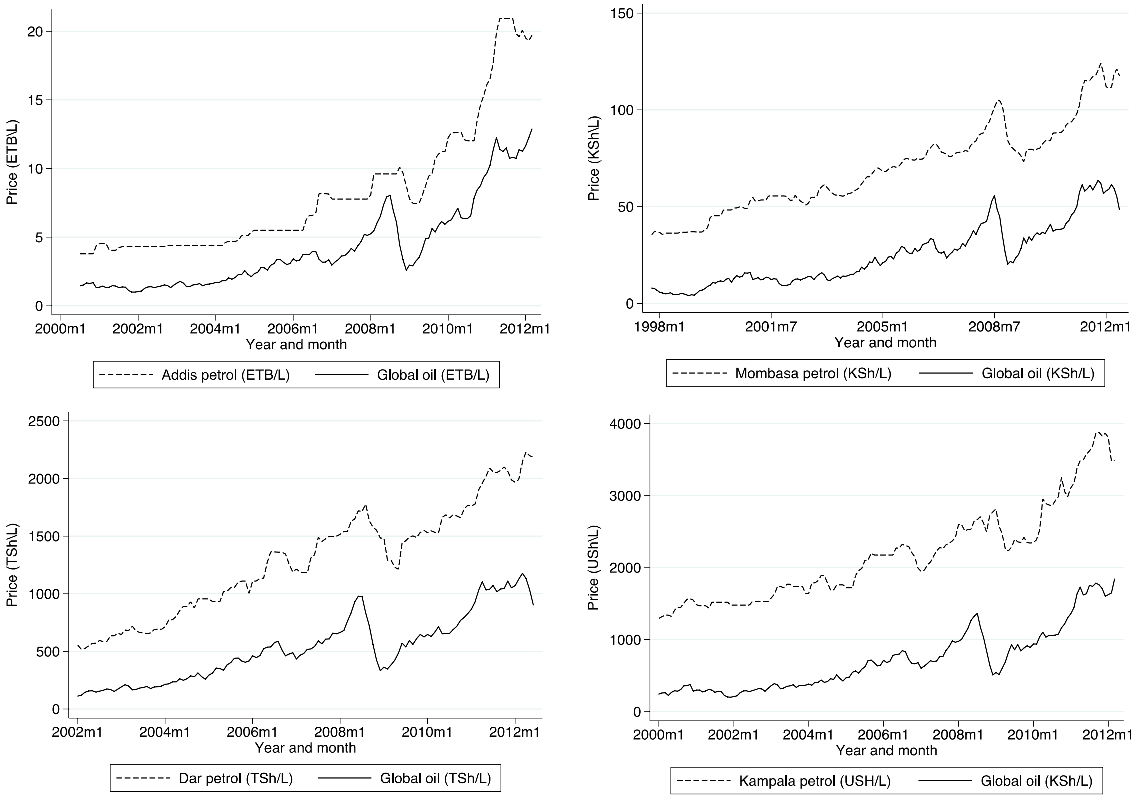


Figure 8. Diagram of Empirical Strategy

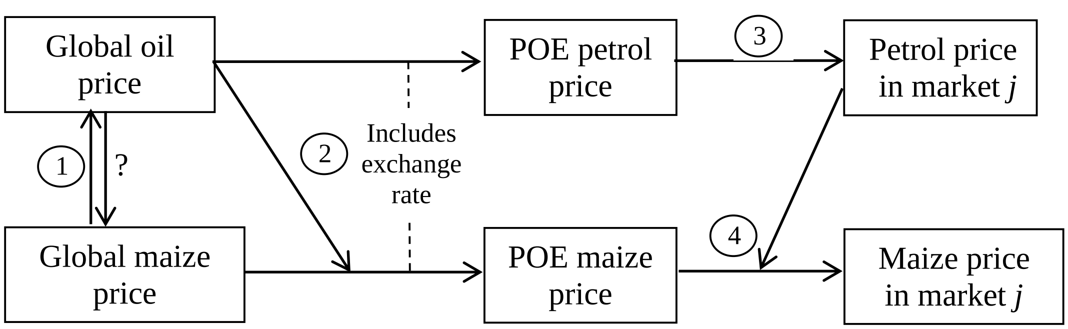


Figure 9. Normalized, average residuals by month from the first-stage ECM results, POE maize

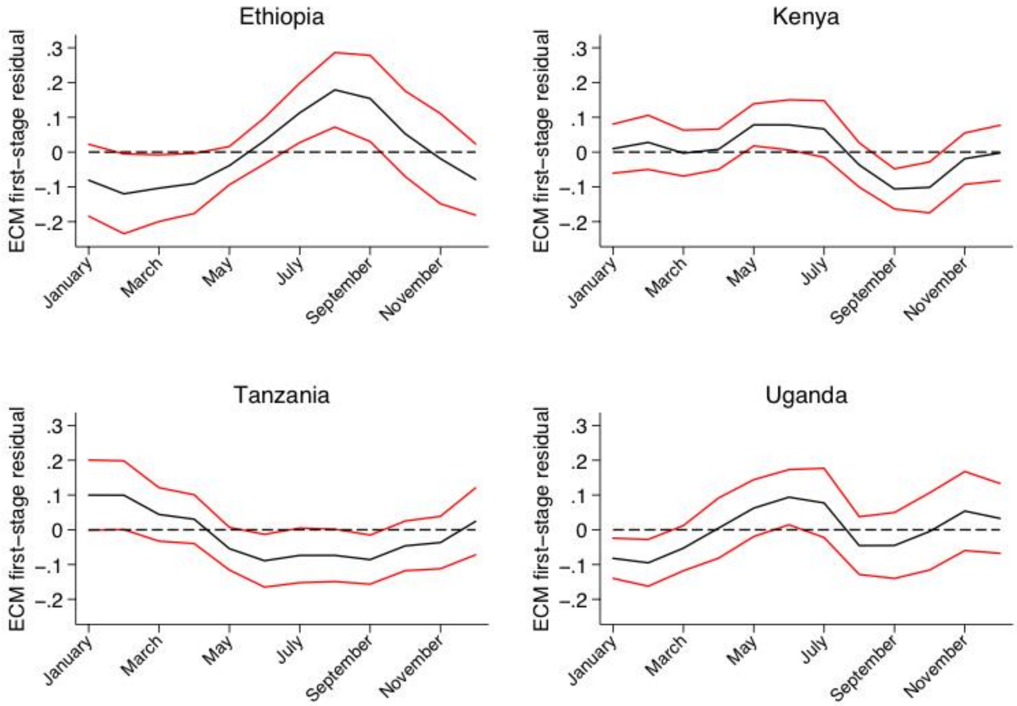


Figure 10. Estimated maize price elasticities with respect to global oil prices, as a function of distance from port of entry

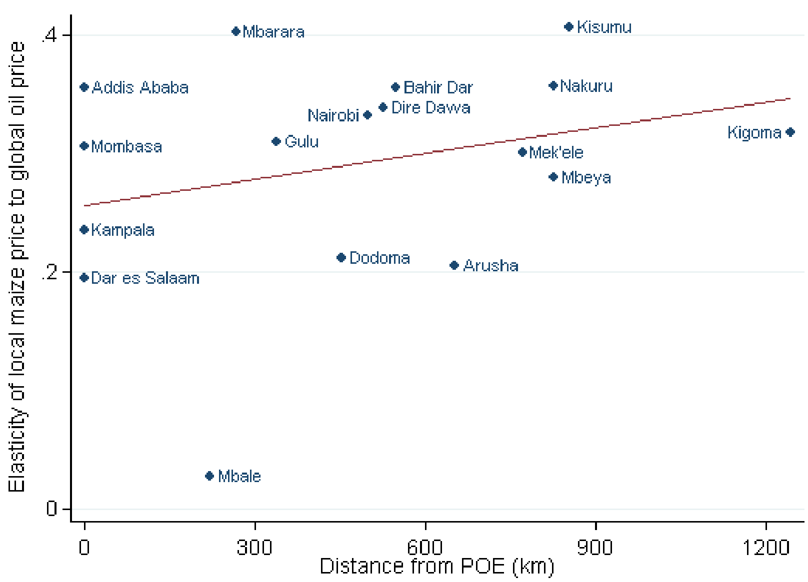


Table 1. Hectares under cultivation, by crop, 2007-2010

	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. 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 4. 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 5. 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 6. 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; ER is "exchange rate"

Table 7. 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 8. 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 9. 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 10. 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 11. 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 12. 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 13. 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

ALL APPENDICES INTENDED FOR ONLINE PUBLICATION ONLY

Appendix A: Exploring the fertilizer price pathway

A detailed look at Kenya

Kenya is the only country with substantial use of inorganic fertilizer during the study period. Because nitrogen fertilizer is most commonly produced from natural gas (using the Haber-Bosch process), the price of which is closely linked to the price of oil, a link between global oil prices and maize prices in Kenya could be partly due to changes in production costs. In this appendix, we explore this possibility.

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 A1 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 A2 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 A1 and A2. All coefficients have the expected sign. The estimate DAP-oil price elasticity is 0.84, very close to unity (Table A1). 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 9-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 A3.[16] 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 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

[16] 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.

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 A4 and A5. 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, increases in the DAP price negatively impact price spreads between POE maize and local maize (Table A4). Furthermore, in Table A5 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 A6 and A8 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 A7 and A9 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 A9), 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 A7), 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 A7). While this could be reflective of a real price effect,[17] 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.

[17] 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 A1. Global Maize and Fertilizer prices, 1990-2012 (Nominal)

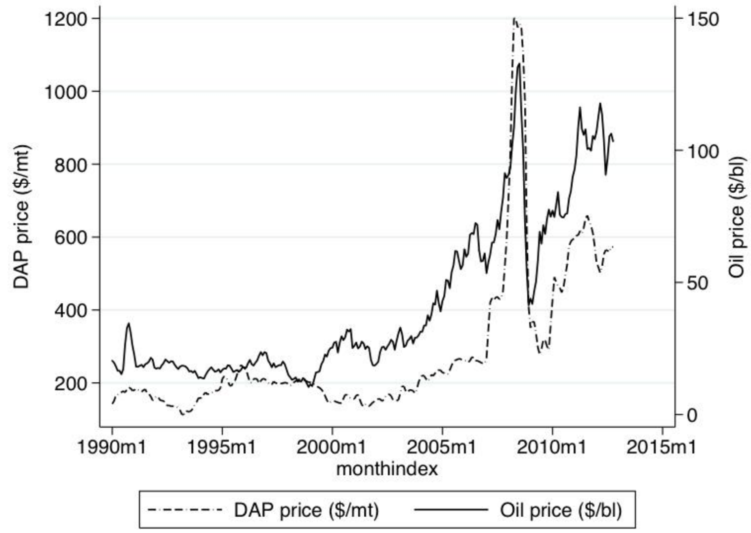


Figure A2. Global DAP prices and DAP prices in Nairobi, KY, 2007-2011 (Nominal)

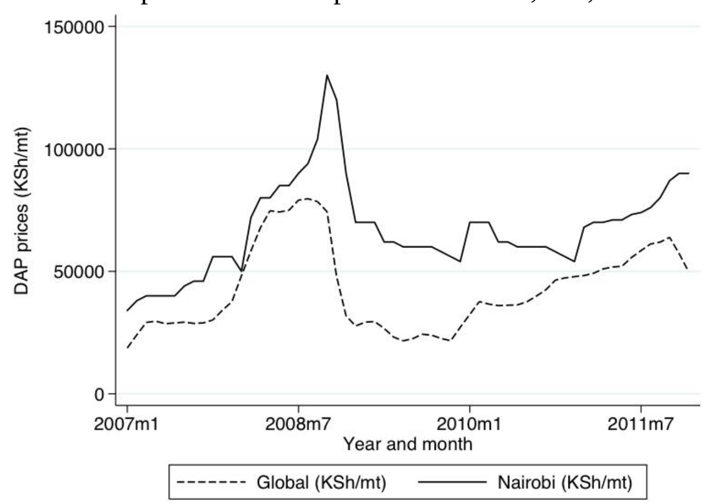


Table A1. Global DAP and global oil, first stage ECM results, 1990-2012

	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 A2. 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 A3. 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 A4. 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 A5. 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 A6. 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 A7. POE maize and global maize, fertilizer and oil, first-stage ECM results

	(1)	(2)	(3)	(4)
	Ethiopia	Kenya	Tanzania	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: dep. 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 A8. 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: dep var is change in nominal POE maize price; st errors in parens; *** sig at 1%, ** at 5%, * at 10%

Table A9. 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 B: Global oil and global maize price relationships

Empirical approach

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 E has results of all cointegration tests in the paper). 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 B1, 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.

Results

Table B1 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 B1 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.

Figure B1. Global Maize and Oil prices, Oct 2006 – Nov 2012 (Nominal)

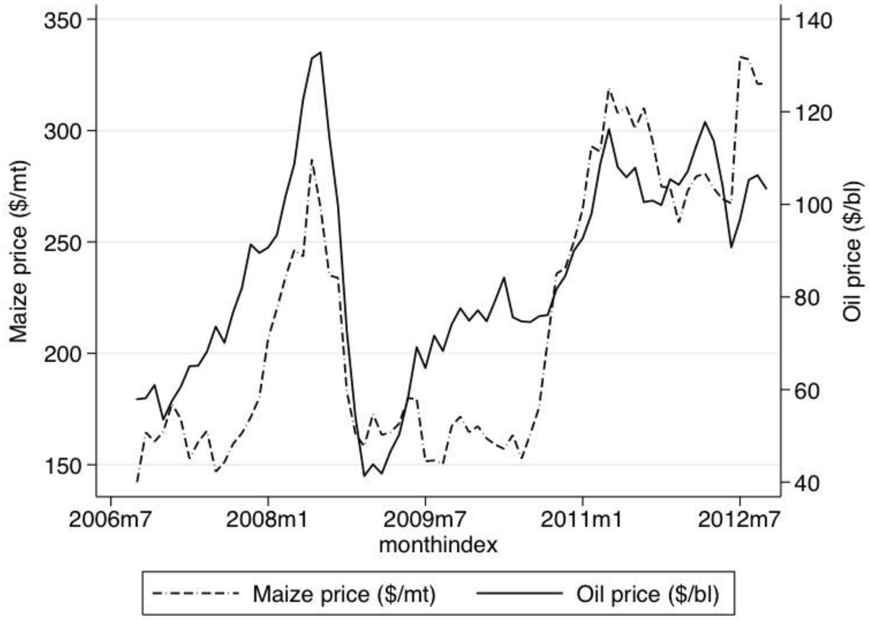


Table B1. VAR results, global oil and maize prices (Nominal)

	(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

Appendix C: Testing the 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:

(C1) $\Delta M_t^{POE} = \vartheta_1\left[M_{t-1}^{POE} - \beta_1 M_{t-1}^{G} - \beta_2 F_{t-1}^{G} - \beta_3 ER_{t-1} - \alpha\right] + \sum_{k=1}^{K}\{\delta_{5k-2}\Delta M_{t-k}^{POE} + \delta_{5k-1}\Delta M_{t-k}^{G} + \delta_{5k}\Delta F_{t-k}^{G} + \delta_{5k+1}\Delta ER_{t-k} + \delta_{5k+2}\Delta CPI_{t-k}\} + \nu_{1t}$

(C2) $\Delta M_t^{G} = \vartheta_2[M_{t-1}^{POE} - \beta_1 M_{t-1}^{G} - \beta_2 F_{t-1}^{G} - \beta_3 ER_{t-1} - \alpha] + \sum_{k=1}^{K}\{\gamma_{5k-2}\Delta M_{t-k}^{POE} + \gamma_{5k-1}\Delta M_{t-k}^{G} + \gamma_{5k}\Delta F_{t-k}^{G} + \gamma_{5k+1}\Delta ER_{t-k} + \gamma_{5k+2}\Delta CPI_{t-k}\} + \nu_{2t}$

(C3) $\Delta F_t^{G} = \vartheta_3[M_{t-1}^{POE} - \beta_1 M_{t-1}^{G} - \beta_2 F_{t-1}^{G} - \beta_3 ER_{t-1} - \alpha] + \sum_{k=1}^{K}\{\rho_{5k-2}\Delta M_{t-k}^{POE} + \rho_{5k-1}\Delta M_{t-k}^{G} + \rho_{5k}\Delta F_{t-k}^{G} + \rho_{5k+1}\Delta ER_{t-k} + \rho_{5k+2}\Delta CPI_{t-k}\} + \nu_{3t}$

(C4) $\Delta ER_t = \vartheta_4[M_{t-1}^{POE} - \beta_1 M_{t-1}^{G} - \beta_2 F_{t-1}^{G} - \beta_3 ER_{t-1} - \alpha] + \sum_{k=1}^{K}\{\tau_{5k-2}\Delta M_{t-k}^{POE} + \tau_{5k-1}\Delta M_{t-k}^{G} + \tau_{5k}\Delta F_{t-k}^{G} + \tau_{5k+1}\Delta ER_{t-k} + \tau_{5k+2}\Delta CPI_{t-k}\} + \nu_{4t}$

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 C4 equations are shown in Table C1. 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 two 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:

(C5) $\Delta F_t^{POE} = \mu_1\left[F_{t-1}^{POE} - \varphi_1 F_{t-1}^{G} - \varphi_2 ER_{t-1} - \pi\right] + \sum_{k=1}^{K}\{\sigma_{4k-1}\Delta F_{t-k}^{POE} + \sigma_{4k}\Delta F_{t-k}^{G} + \sigma_{4k+1}\Delta ER_{t-k} + \sigma_{4k+2}\Delta CPI_{t-k}\} + \varepsilon_{1t}$

(C6) $\Delta F_t^{G} = \mu_2[F_{t-1}^{POE} - \varphi_1 F_{t-1}^{G} - \varphi_2 ER_{t-1} - \pi] + \sum_{k=1}^{K}\{\omega_{4k-1}\Delta F_{t-k}^{POE} + \omega_{4k}\Delta F_{t-k}^{G} + \omega_{4k+1}\Delta ER_{t-k} + \omega_{4k+2}\Delta CPI_{t-k}\} + \varepsilon_{2t}$

(C7) $\Delta ER_t = \mu_3[F_{t-1}^{POE} - \varphi_1 F_{t-1}^{G} - \varphi_2 ER_{t-1} - \pi] + \sum_{k=1}^{K}\{\partial_{4k-1}\Delta F_{t-k}^{POE} + \partial_{4k}\Delta F_{t-k}^{G} + \partial_{4k+1}\Delta ER_{t-k} + \partial_{4k+2}\Delta CPI_{t-k}\} + \varepsilon_{3t}$

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 C7 equations are shown in Table C2. 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 C1. 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 C2. 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 D: Policy background and market details 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.

Additional data details for study markets

Table D1 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 D1 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 transport costs to Mombasa are lower for international exporters than those to more centrally located cities.

Table D2 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.

Table D1. 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 D2. 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

Appendix E: Results of rank tests 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:

(E1) $$\Delta x_t = \alpha(\mu + \beta x_{t-1} + \varphi t) + \sum_{i=1}^{s}[\gamma + \Gamma_{\mathrm{i}}\Delta x_{t-i} + \psi t] + \varepsilon_t$$

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 E1), 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 E1 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 E2 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 E3 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 E4 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 E5 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 E1. 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	Trace statistics 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 E2. 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 E3. 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 E4. 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 E5. 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