

CLIMATE VOLATILITY AND TRADE POLICY IN TANZANIA

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Abstract

Climate volatility affects agricultural variability, and an extreme climate outcome has the potential to detrimentally affect food supply and prices in a given country. International trade has the potential to reduce the impacts of climate-induced food production variability, although it may further expose the country to international price volatility. This study focuses on Tanzania and finds that global production volatility has very little effect on domestic grains prices due to the country's limited integration with the international grains market. Almost all the price volatility in grains is attributable to domestic production volatility. At the same time, an export ban that was a response to the 2005-2008 food price crisis increases potential domestic grains price volatility. Rural agricultural households that are net sellers of grains, or rely on revenue from grains production as their primary source of income, may be particularly vulnerable to high income volatility through climate-induced production variability. If Tanzania experiences extremely positive shocks to grains production – due to exceptionally good climate outcomes for example – total revenue from grains falls by 2 percent under the 2001 national trade regime, with the revenue decline becoming 5 percent if there is an export ban on grains.

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1. INTRODUCTION

There is substantial evidence that the frequency and intensity of climate extremes may change in the coming decades (Diffenbaugh et al., 2005; Easterling et al., 2000; IPCC, 2007), with these changes being particularly important for agriculture (Lobell et al., 2008; White et al., 2006; Mendelsohn et al., 2007). Sub-Saharan African countries, like Tanzania, are particularly sensitive to climate extremes due to the reliance in many countries on rain-fed subsistence agriculture. Large shares of agricultural production are for private consumption (Narayan and Walmsley, 2008), and an output reducing climate outcome could severely affect the food availability in the afflicted countries through both reductions in food supply as well as increases in food price. The food price crisis of 2005-2008 is estimated to have impoverished 105 million people (Ivanic and Martin, 2008), and there is evidence that extreme climate events that reduce agricultural productivity can severely increase poverty in Sub-Saharan African countries through impacts on prices and incomes (Ahmed et al., 2009a).

However, there is heterogeneity in climate across countries, and so international agricultural markets may allow for a pooling of the risk of local (or national) climate extremes effects, with farmers in countries that are less severely affected by climate changes selling excess supply to meet the excess demand from consumers in the more severely affected regions. In the medium to long run, declines in agricultural production and trade arising from climate extremes in some countries might be offset by increases in production in other regions and exports of other products. This pooling of risk would be concurrent with a more efficient global reallocation of resources as countries adjusted production to be consistent with the potential changes in comparative advantage. In the short run, when resources may not be easily reallocated across economies, open trade regimes have the potential to reduce domestic price volatility. For example, an open trade regime restricts the increase in food prices to the import parity price in the event of a severe productivity shock, such as a drought (Dorosh et al., 2007).

Despite the apparent benefits of greater international trade as a mechanism to reduce food supply variability and food price volatility – both important for food security - the trade policy response to climate volatility may in fact be one of greater international agricultural protection. Reilly et al (1994) identifies concern about national food security from a supply perspective as an argument in favor of greater trade restriction, with restrictions becoming attractive mechanisms to maintain food supply objectives. Following this reasoning, the food price crisis of 2005-2008 saw several countries erect export restrictions to increase domestic food availability. Tanzania, for example, currently has export bans on maize (FAO, 2009). However, as Mitra and Josling (2009) point out, the price insulation introduced through export restrictions may have blocked supply responses to higher international prices, and ultimately may not have been welfare improving. The substantial informal exports of maize to Kenya and neighboring countries in the presence of the export ban, as reported by RATIN (2009) and Janyne et al. (2009), may be evidence of a response to regional differences in prices.

Due to the potentially important role that trade policy can play in mitigating the effects of climate on production, the interaction of international trade with agricultural production shocks arising from climate change has been explored in the literature (e.g. Tobey et al., 1992; Reilly et al., 1994; Tsigas

et al., 1997; Randhir and Hertel, 2000). At the same time, the literature has knowledge gaps and uncertainty in how trade policy may help in adapting to climate extremes. First, these studies do not consider the impact of changing climate volatility and extremes. Second, the scope of many of these studies was constrained by the data limitations that prohibited analysis of specific African countries. Reimer and Li's (2009) more recent examination of the cereal grain and oilseeds trades finds that world trade volumes will need to increase if yield variability increases. However, this analysis was unable to examine the complex interaction of factor incomes and prices in determining how household level welfare – especially of poor households – may vary, as has been shown in the trade and poverty literature (e.g. Hertel et al., 2004; Hertel and Winters, 2006; Hertel et al., 2009) and in recent analyses of climate change and poverty (Ahmed et al., 2009a, 2009b).

This study will thus examine the impact of global historical grains productivity volatility attributable to climate volatility on prices and factor incomes in Tanzania – a small developing country where grains production variability may increase due to changing climate volatility (Ahmed et al., 2009b). The interaction between trade policy and the climate-induced grains production volatility will be examined by considering the impacts under a benchmark trade regime and a trade regime where Tanzania has imposed an export ban on grains.

2. TANZANIAN GRAINS TRADE AND INTERANNUAL PRODUCTION VOLATILITY

Tanzanian trade policy thus emphasizes regional integration and the multilateral system, as reflected in the National Trade Policy (Tanzania, 2003), which in turn describes itself as having the goal of guiding the country from a supply-constrained economy to one with competitive export-led growth. Growing exports have been credited with an important role in raising the growth rate from two percent per annum in 1990-95 to six percent in 2000-03 (Integrated Framework, 2005). The National Trade Policy (NTP), however, provides only a weak and superficial treatment to agriculture enhancing policies, even though crop exports accounted for about 23 percent of the total export value in 2001 (Dimaranan, 2006). There also appears to be little co-ordination of trade, agriculture, and poverty reduction strategies, despite the importance of sustaining export growth placed in the National Strategy for Growth and Reduction of Poverty (Tanzania, 2005).

The 2001 trade data from the GTAP Database (Dimaranan, 2006) provide a more substantial perspective of Tanzanian trade. The aggregate category Other Crops⁴ accounts for 22 percent of the total USD 1.5 billion in exports, while Grains are 1.28 percent of exports (Table 1). Aside from agriculture, Manufacturing, and Other Food and Beverages are also major exports. At the same time, Tanzania almost half of Tanzania's imports are Manufacturing goods. Grains account for 69 percent of agricultural imports (2.9 percent of all imports).

⁴ Including export crops like tobacco, tea, coffee, cocoa, and cloves.

Table 1: Goods and Services as Shares of Total Exports and Imports for Tanzania (2001)

Sector	Share of Exports (%)	Share of Imports (%)
	I	II
Grains	1.29	2.88
Other Crops	21.78	1.09
Textiles' Raw Material	3.14	0.02
Livestock	1.51	0.15
Fishing	0.38	0.03
Oil	0.00	0.00
Coal & Gas	0.00	0.00
Forestry & Mining	3.79	0.33
Vegetable Oils	0.17	2.18
Processed Livestock	0.53	0.60
Processed Rice	0.24	1.49
Sugar	0.54	0.95
Other Food & Beverages	12.19	2.66
Textiles & Wearing Apparel	4.92	6.02
Lumber	0.41	0.59
Manufacturing	24.71	47.21
Petroleum & Coal Products	0.00	6.29
Transp. Equipment Manufacturing	0.34	1.48
Construction & Utilities	0.94	0.21
Trade	7.08	4.77
Transportation	9.98	7.31
Services	4.77	9.36
Education, Government, Housing	1.31	4.37
Total	100.00 (USD 1.5 billion)	100.00 (USD 2.3 billion)

Source: Dimaranan (2006)

Table 2: Tanzanian Grains Trade Patterns and International Interannual Production Volatility

Region	Import Share (%)	Export Share (%)	Interannual Grains Production Change Volatility (1971-2001)	Correlation Coefficients Between Foreign & Tanzanian Production Volatilities
	I	II	III	IV
Oceania	81.13	1.29	25.36	-0.11
East Asia	4.59	8.84	4.37	0.34
South East Asia	0.03	2.75	4.50	0.08
South Asia	4.76	0.48	8.69	0.17
US-Canada	2.39	15.63	25.33	0.04
Latin America & Caribbean	2.24	3.66	7.23	0.02
Western Europe	2.77	33.19	9.70	0.15
Eastern Europe & Former USSR	0.04	3.72	18.56	-0.04
Middle East & North Africa	0.26	2.37	9.68	-0.21
Tanzania	n.a.	n.a.	22.27	n.a.
Eastern Africa	0.00	0.00	12.18	-0.04
Southern Africa	1.07	2.32	58.91	-0.19
Rest of Sub-Saharan Africa	0.41	1.40	8.10	0.08
Total	100 (USD 67 mil.)	100 (USD 19 mil.)		
Average			16.53	0.02

Source: Columns I and II (Dimaranan, 2006), columns III and IV (authors' estimates).

From columns I and II in Table 2, it can be seen that a handful of countries are important trading partners to Tanzania for Grains. Oceania (primarily Australia) and South Asia (primarily India) were responsible for 86 percent of Grains imported into Tanzania. The USA and Canada, Western Europe and East Asia are the major destinations for Tanzanian Grains, accounting for 57 percent of Grains exports.

These trade patterns reflect Tanzania's myriad trade agreements and preferences (circa 2001), and the barriers that it places on imports, as well as those faced by its exports. For example, Western Europe imposes almost no tariffs on Tanzanian imports, with the exception of Sugar. Oceania also has few and low tariffs against Tanzanian goods, while African regions tend to have higher rates of protection against imports from Tanzania. There is thus a great deal of heterogeneity in the tariffs faced by Tanzanian exports in different export markets. In contrast, Tanzanian tariffs against imports from the rest of the world tend to be more homogeneous, with the rates faced by different source countries similar to the world average rates. East Africa and Oceania are exceptions, enjoying zero-tariffs on several of their aggregate exports to Tanzania.

Intuitively, climate volatility in major grains exporting or importing countries that translates into grains production volatility would affect Tanzania, such as through changes to the import price and

changes to demand for Tanzanian Grains. Column III describes the standard deviation of interannual changes in grains production for the period 1971-2001⁵ for the various regions of the world. The detrended interannual percent changes in Grains production for each region that underlie these standard deviations can thus be conceptualized as being attributable to idiosyncratic shocks, such as the climate, following Ahmed et al. (2009a). The results standard deviations of interannual Grains production changes can thus be considered to be a reflection of the agricultural impacts of climate volatility.

Major Grains trading regions like Oceania and US-Canada are found to have interannual change volatilities that are higher than Tanzania's. When the correlation coefficients for the interannual changes in Grains production in Tanzania and the interannual changes in Grains production in other regions are calculated (column IV, Table 2), it is found that there is very low correlation between the interannual production changes in Tanzania and changes in other countries. This supports the intuition that climate impacts in a given year are heterogeneous across countries. For example, a bad harvest in Tanzania may occur in the same year that South Africa experiences a bumper crop, and vice versa.

3. ANALYSIS

We are now in a position to analyze the impact of global interannual production change volatility on food prices and incomes in Tanzania. In order to estimate the changes in consumer prices and earnings stemming from changes to agricultural productivity due to climate effects, we employ the widely used GTAP computable general equilibrium simulation model.

We begin with the GTAP Database Version 6 (Dimaranan, 2006) and use this with a modified version of the standard GTAP model (Hertel, 1997). We retain the empirically robust assumptions of constant returns to scale and perfect competition, and introduce factor market segmentation which is important in countries where the rural sector remains a dominant source of poverty following the methodology of Keeney and Hertel (2005). Farm and non-farm mobility of factors are restricted by specifying a constant elasticity of transformation function which "transforms" farm employed versions of labor and capital into non-farm uses and vice-versa. This allows for persistent wage differences between the farm and non-farm sectors, and is the foundation of the intersectoral distributional analysis. In order to parameterize these factor mobility functions we draw on the OECD's (2001) survey of agricultural factor markets. We assume a constant aggregate level of land, labor, and capital

⁵ Production data for maize, sorghum, and rice from FAO (2010) for the period 1970-2001 was applied to the 2000-2002 average international prices of those commodities to determine a Grains production time series in 2000-2002 average USD. The interannual percent changes in Grains production were then calculated for each region, and after detrending the time series, the standard deviations were calculated as measures of the distribution of interannual percent changes in Grains production. The international price of maize was taken to be US No. 2 Yellow US Gulf, of rice was taken to be White Broken Rice, Thai A1 Super, f.o.b Bangkok, and of sorghum to be US No. 2 Yellow US Gulf.

employment reflecting the belief that the aggregate supply of factors is unaffected by the climate shocks that are affecting Grains production.

The model is also adjusted to distinguish between lands with different biophysical characteristics, following the approach of Hertel et al (2009a), distinguishing land by Agro-Ecological Zone (AEZ), based on the data of Lee et al (2009) and Monfreda et al (2009). The model is then calibrated such that simulations of estimated historical productivity volatility of Grains for the 1971-2001 period replicate observed historical price volatility⁶

First, we simulate the interannual Grains productivity change volatility for all countries of the world, assuming a triangular distribution with the standard deviations described in column III (Table 2), and a mean interannual change of zero, as in Valenzuela et al. (2008). Productivity is difficult to measure, and so the estimated production volatilities of Table 1 are used as proxies of productivity volatilities. This is not unreasonable since the simulations will shock output augmenting technology used in the sector, directly related to sectoral productivity. Also, the detrended time series of interannual percent changes in Grains production for each region that underlie the volatilities are assumed to be attributable to idiosyncratic climate shocks, following Ahmed et al. (2009a). The historical productivity volatility is thus assumed to be a reflection of the historical climate volatility.

These simulations are conducted under the trade regime that prevailed under the 2001 benchmark year's world economy, and under the condition that agricultural land and capital are immobile across sectors. This allows for the modeling for short-run behavior, when farmers and other agents are unable to mobilize factors other than labor in response to a climate shock like a drought or heat wave. We then simulate Grains production volatility only in Tanzania, to help provide a sense of the relative importance of domestic productivity volatility versus productivity volatility in trading partners. Given Tanzania's low level of integration with the international Grains market, it is expected that most of the price volatility – and subsequent effects – will be driven by the domestic productivity volatility.

The following set of stochastic simulations is conducted with the same shocks, but under an alternative trade regime. As mentioned earlier, Tanzania introduced export bans on grains such as maize in response to the 2005-2008 food price crisis. The model is thus adjusted to force Tanzanian Grains exports to be fixed, simulating the export ban. Tanzania reduced import restrictions on grains as a response to the food price crisis, and so the import restricting policies will not be considered, although there are studies that have examined the effects of import restrictions for other Africa countries (see Dorosh et al., 2007 and Haggblade et al., 2009).

We now turn to the simulation to understand the full implications of the export ban on the volatility of Grains prices, factor income, and Tanzanian welfare.

⁶ Please see Appendix A for details of model calibration

3.1 SIMULATION RESULTS

Table 3 describes the impact of the Grains production volatility, considering the case where global interannual Grains production changes vary and the case where only Tanzania's interannual production changes vary. Comparing the price volatilities under global productivity volatility (columns I-III) to the price volatilities under Tanzanian-only production volatility (column IV-VI), it can be seen that the market price of Grains in Tanzania is only slightly affected by global productivity volatility. When global productivity volatility is considered, the volatility of the market price of Grains is almost the same as the volatility of the price of domestic Grains, and the import price volatility is found to be much lower than either. The market price volatility under global production volatility and the market price volatility under Tanzania-only productivity volatility (columns I and IV) also seem similar, indicating that Tanzanian price volatility is driven mostly by domestic factors. This is not surprising given Tanzania's very limited integration with the formal international Grains market.

The price of Processed Rice is also found to be highly volatile. Since Grains account for 98.7 percent of the Processed Rice industry's intermediate inputs, the volatilities in Grains productivity and price translates into volatility into interannual production change volatility for Processed Rice that is higher than Grains production volatility.

The price volatilities of the other commodities are strongly influenced by volatilities in factor incomes. The mechanisms can be illustrated by considering a specific draw from the Tanzanian interannual Grains productivity change distribution. Specifically, let us examine the case of when Tanzanian Grains productivity experiences a 15 percent interannual increase⁷, representing a beneficial climate extreme.

When there is a 15 percent increase in Grains productivity (and output), the Grains price declines by 17 percent (Table 4). Due to the greater supply and lower price, downstream industries are able to expand, with Processed Rice experiencing the largest percent increase (28 percent). The prices of Processed Rice and Other Food and Beverages decline due to the sharp price decrease in Grains – those industries' most important intermediate input. Expanding industries' higher demand for primary factors pushes up most factor prices. Exceptions are the prices of capital, land and natural resources in agriculture. Due to higher demand from expanding non-agricultural industries, labor leave crop industries, pushing down the demand for agriculture-specific factors, reducing their rents. Generally, the higher factor prices push up commodity, aside from those industries where the price declines of intermediate inputs dominate (e.g. Processed Rice).

⁷ Following Ahmed et al. (2009a), we apply the estimated standard deviation for Tanzania (Table 1) to a mean-zero normal distribution. This provides a stylized probability distribution from which we determine the productivity change that would occur at the 75th percentile.

When the global historical Grains productivity volatility is simulated while Tanzania has an export ban on Grains in place, the price volatilities of Grains and commodities that use Grains an intermediate input are found to be much greater than in the absence of the ban (Table 5).

Table 3: Price Volatility in Tanzania Due to Simulated Grains Production Volatility under Benchmark Trade Regime, Measured as Standard Deviations of Interannual Percent Changes

	Global Production Volatility Sim.			Tanzania Production Volatility Sim.		
	Market Price ⁸	Domestic price	Import Price	Market Price	Domestic price	Import Price
	I	II	III	IV	V	VI
Grains	33.9	34.3	19.6	31.0	31.4	0.4
Other Crops	1.8	1.8	0.8	1.2	1.2	0.0
Textiles' Raw Material	1.1	1.1	1.1	0.0	0.1	0.0
Livestock	6.0	6.1	1.3	5.3	5.4	0.0
Fishing	10.1	10.1	0.5	8.4	8.5	0.0
Oil	0.8	0.9	0.8	0.0	0.0	0.0
Coal & Gas	1.6	2.0	1.6	0.0	0.6	0.0
Forestry & Mining	5.3	5.3	0.3	4.1	4.1	0.0
Vegetable Oils	1.0	1.9	0.4	0.5	1.3	0.0
Processed Livestock	5.1	5.4	0.6	4.2	4.4	0.0
Processed Rice	17.5	33.6	7.7	15.7	30.7	0.0
Sugar	0.7	1.8	0.6	0.2	1.2	0.0
Other Food & Beverages	5.2	5.4	1.3	3.9	4.1	0.0
Textiles & Wearing Apparel	1.9	2.5	0.1	1.5	2.0	0.0
Lumber	2.9	3.2	0.2	2.1	2.3	0.0
Manufacturing	0.5	1.0	0.1	0.4	0.8	0.0
Petroleum & Coal Products	0.7	1.5	0.7	0.0	1.2	0.0
Transp. Equipment Manufacturing	1.4	1.6	0.1	0.8	0.9	0.0
Construction & Utilities	3.9	3.9	0.2	2.4	2.4	0.0
Trade	3.9	4.1	0.1	3.0	3.1	0.0
Transportation	2.3	2.8	0.3	1.7	2.2	0.0
Services	2.4	2.7	0.2	1.9	2.2	0.0
Education, Government, Housing	3.5	4.0	0.2	2.7	3.0	0.0

Source: Authors' simulations

⁸ Price faced by private consumers

Table 4: Impact of Interannual Tanzanian Grains Productivity Increase of 15 Percent under Benchmark Trade Regime

	Output Change (%)	Market Price Change (%)
	I	II
Grains	15.0	-16.9
Other Crops	-0.2	0.7
Textiles' Raw Material	-0.3	0.0
Livestock	0.8	3.2
Fishing	1.1	5.1
Oil	-0.1	0.0
Coal & Gas	-0.6	-0.1
Forestry & Mining	0.3	2.3
Vegetable Oils	-0.7	0.7
Processed Livestock	1.5	2.5
Processed Rice	28.3	-16.6
Sugar	-2.2	0.7
Other Food & Beverages	1.9	-2.4
Textiles & Wearing Apparel	-1.2	1.1
Lumber	-0.6	1.3
Manufacturing	-1.3	0.4
Petroleum & Coal Products	-0.9	0.7
Transp. Equipment Manufacturing	-1.5	0.5
Construction & Utilities	-0.3	1.3
Trade	0.2	1.8
Transportation	-0.5	1.2
Services	-0.4	1.2
Education, Government, Housing	0.1	1.7

Source: Authors' simulations

Table 5: Price Volatility in Tanzania Due to Simulated Grains Production Volatility under a Grains Export Ban, Measured as Standard Deviations of Interannual Percent Changes

	Market Price	Domestic price	Import Price
	I	II	III
Grains	38.2	38.6	19.7
Other Crops	1.3	1.3	1.0
Textiles' Raw Material	1.4	1.3	1.4
Livestock	4.8	4.8	1.8
Fishing	7.0	7.0	0.5
Oil	0.9	1.0	0.9
Coal & Gas	1.6	2.2	1.6
Forestry & Mining	3.3	3.3	0.3
Vegetable Oils	0.7	1.3	0.5
Processed Livestock	3.5	3.6	0.7
Processed Rice	20.1	37.8	7.9
Sugar	0.7	1.3	0.6
Other Food & Beverages	6.4	6.6	1.4
Textiles & Wearing Apparel	1.2	1.6	0.1
Lumber	1.7	1.9	0.2
Manufacturing	0.3	0.6	0.2
Petroleum & Coal Products	0.8	1.1	0.8
Transp. Equipment Manufacturing	0.7	0.8	0.1
Construction & Utilities	2.1	2.1	0.2
Trade	2.4	2.6	0.1
Transportation	1.4	1.7	0.3
Services	1.6	1.8	0.2
Education, Government, Housing	2.1	2.4	0.2

Source: Authors' simulations

Figure 1 illustrates the basic mechanism by which an export ban increases Grains price volatility. In the base period, domestic Grains demand and domestic Grains supply are characterized by D and S_0 . If the domestic price of Grains is P_0 then the quantity demanded is Q_0 , with there being no imports or exports of Grains. P_M and P_X are the import and export parity prices respectively, within which prices normally vary in an open economy. In a small open economy, if the Grains supply increases or decreases, then in the short run, the impact on Grains price will be forced to remain within the import parity upper bound and the export parity lower bound. For example, if there is a drought that reduces supply, then the Grains price will rise and consumption would fall. However, the price increase would not be greater than the import parity price. Similarly, in the event of a large increase in Grains supply – due to a year of exceptionally good weather, for example – then the Grains price cannot decrease below that of the export parity price.

If there is a year of favorable climate, the Grains supply schedule shifts outwards, from S_0 to S' . Domestic consumers now demand Q' Grains at price P_X , and the country exports a quantity of Grains equal to Q'' minus Q' . However, in the presence of an export ban, the price would continue to fall to P_{EB} .

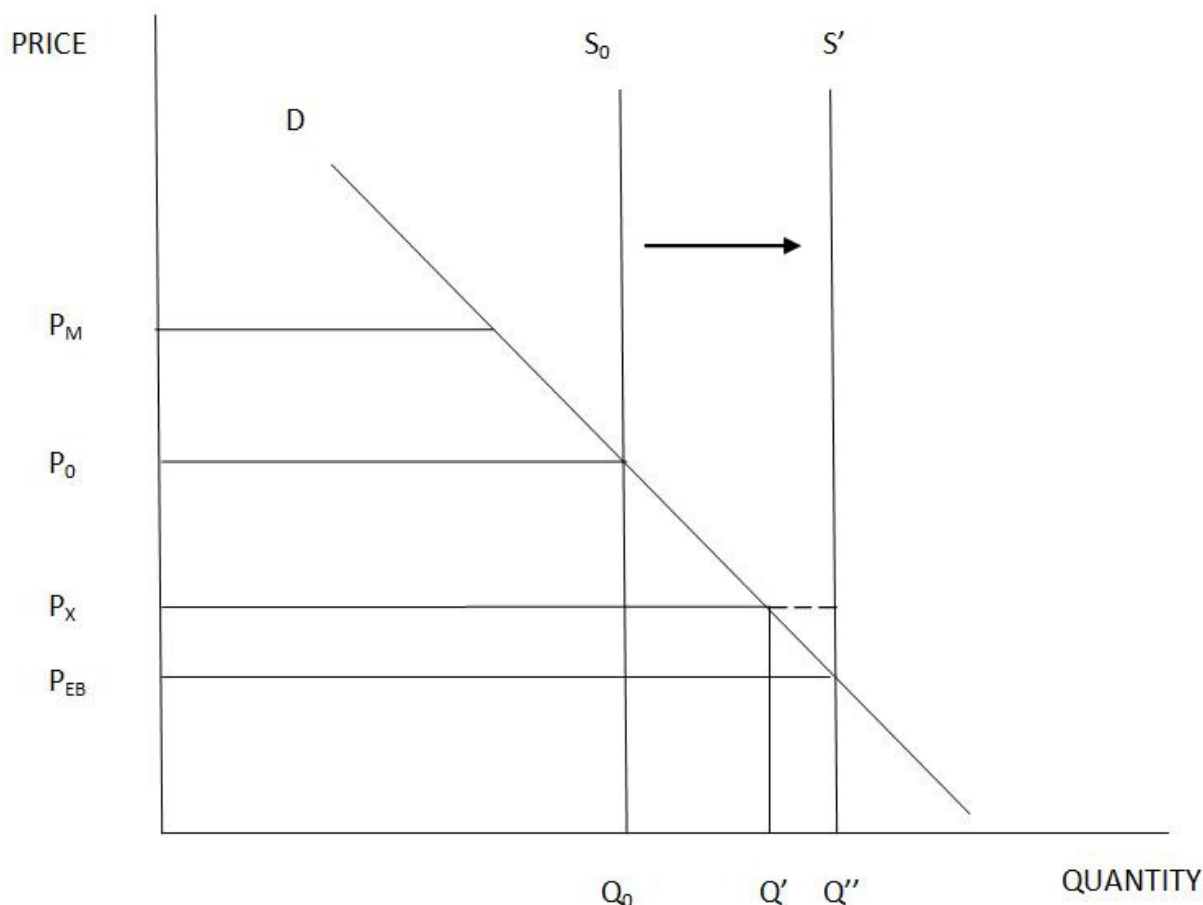


Figure 1: Mechanism by which Export Bans Potentially Lead to Lower Prices during Short Run Supply Increase

So, in the years when there are sufficiently high (positive) draws from the distribution of interannual Grains productivity changes for Tanzania, the price of Grains may drop below the export parity price if there is an export ban in place. The high Grains price volatility translates into higher price volatility for the downstream Processed Rice and Other Food and Beverages commodities.

3.2 POVERTY IMPLICATIONS

When considering the impacts of productivity volatility on poverty, we must account for the impacts on prices as well as factor incomes, since changes in prices will change the cost of living.

Column I and II from Table 6 show how the volatility in cost-of-living adjusted factor incomes for households living on the national poverty vary when global Grains productivity is simulated. Incomes generally tend to be more volatile under the export ban. Households where rents from agriculture-specific capital are an important source of income are particularly vulnerable to high income volatility.

Table 6: Income Effects in Tanzania of Grains Productivity Volatility

	Interannual Global Productivity Volatility		Impacts of 15% Interannual Increase in Tanzanian Grains Productivity (%)	
	Benchmark Trade Regime	Under Export Ban	Benchmark Trade Regime	Under Export Ban
	I	II	III	IV
Land Rent	6.9	8.7	-2.8	-5.9
Unskilled Labor - Agricultural	8.4	9.8	5.3	6.4
Skilled Labor- Agricultural	7.2	8.4	4.4	5.4
Unskilled Labor - Non-agricultural	6.2	6.1	3.6	3.5
Skilled Labor- Non-agricultural	6.0	6.3	3.5	3.8
Capital- Agricultural	11.1	13.8	-5.0	-8.2
Capital- Non-Agricultural	6.0	6.3	3.5	3.7

Source: Authors' simulations

If we focus on the scenario where Tanzania experiences a 15 percent increase in Grains productivity – such as due to favorable climate – then we see that most factors experience increases in incomes, while agriculture-specific capital and land experience income declines. This is consistent with our earlier observation. Under an export ban, these changes are all exacerbated, making households dependent on rents from land rents and agricultural capital less well off. The results of columns III and IV thus suggest that urban households are most likely going to benefit from export bans in the event of a Grains productivity increase, through a lower cost of living as well as higher incomes. However, the impacts on rural households are less clear.

A rural household may also benefit from the Grains productivity increase, as long as most of its income is not from land rents or agricultural capital, or from sales of Grains. However, if a rural household is a net-seller of Grains, and all of its income is based on revenue from Grains sales, then the household would be worse off if the Grains price decline is greater than the increase in output. For example, from Table 4, we saw that if Grains productivity (and output) increases by 15 percent, then prices decline by 16.9 percent, leading to a 1.9 percent decline in Grains sector revenue⁹. Now, if there is an export ban in place, the 15 percent increase in Grains productivity leads to a 19.8 percent decline in Grains price, or a 4.8 percent decline in Grains sector revenue. The rural household depending on Grains revenue for its income will thus be worse off under the export ban.

⁹ Revenue = Price X Quantity => % Δ Revenue=% Δ Price + %Δ Quantity

The determination of the precise impact of Grains productivity volatility on poverty thus requires an analysis of consumptions patterns and factor incomes at the household level, including an accounting of how much rural agricultural household income is from crop revenue. Such a precise analysis is beyond the scope of the current study and presents an avenue for future work.

4. CONCLUSION

Climate volatility affects agricultural variability, and an extreme climate outcome has the potential to reduce food supply in a given country. International trade has the potential to reduce the impacts of a food supply shock that a country may experience, although it may expose the country to international price volatility. Many countries instituted trade restrictions as a response to the food price crisis of 2005-2008, including Tanzania which removed import restrictions and instituted an export ban on maize, rice, and other important grains. However, such export bans have the potential to exacerbate domestic food price volatility by allowing prices to drop below what would be an export parity price in more open economies in the event of a large increase in supply. It is not known however whether price volatility induced by climate-induced productivity changes is actually higher under an export ban, or what the implications are for poverty.

This study examines these questions by estimating global grains production volatilities for the period 1971-2001, and simulating them in an economic simulation model under the actual 2001 trade regime and under a counterfactual trade regime where Tanzania has banned grains exports. It is found that due to Tanzania's very limited integration with the international grains market, global production volatility has very little effect on Tanzanian grains prices. Almost all the price volatility in Tanzanian grains is attributable to domestic production volatility. Nonetheless, a Tanzanian export ban does have the effect of increasing domestic grains price volatility. If Tanzania experiences extremely positive shocks to grains production – due to exceptionally good climate outcomes for example – grains prices fall much further under an export ban than under a trade regime without such a ban.

This has severe implications for households living along the poverty line. Since prices are more volatile under an export ban, factor incomes are also much more volatile. Also, rural agricultural households that are net sellers of grains, or rely on revenue from grains production as their primary source of income, are particularly vulnerable. If there is a positive grains productivity change and the percent decrease in the price of grains is much more than percent increase in the sale of grains, then total revenue will fall, to the detriment of that household. Under an export ban, the price of grains falls much further than under a trade regime with no ban, for the same change in output.

Since the variability of Tanzanian grains yield may increase by as much as 34 percent due to climate change (Ahmed et al., 2009b), domestic production volatility may rise by a similar amount. Given the impact that historical production volatility was found to have on food prices and factor incomes, it is imperative that decision makers consider policy responses that will help the most vulnerable groups, like rural agricultural households, so that rising volatility does not also imply rising vulnerability. Decision

makers must also evaluate existing policies, like the export ban examined here, to ascertain that they are best contributing to poverty reduction and climate resilience.

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APPENDIX A: MODEL CALIBRATION

We calibrate the GTAP economic simulation model parameters for Tanzania to be able to replicate historical grain price volatility when historical grains productivity is simulated, following the approach of Valenzuela et al (2009). The approach used can be summarized as broadly following the steps below:

- **Volatility Estimates:** Estimate output and price volatility for a given commodity, with volatility referring to the standard deviation of interannual percentage changes in the variables. The estimated standard deviations are then used to determine the endpoints of a symmetric triangular distribution.
- **Simulation:** Conduct systematic sensitivity analysis (SSA) using the Gaussian Quadrature based approach of Pearson and Arndt (2000), specifically to determine the sensitivity of grains prices with respect to output changes. The extreme value for the grains output SSA is the estimated endpoints of the symmetric triangular distribution described above.
- **Comparison and recalibration:** If the variations in the simulated grains prices for a region are inconsistent with the estimated variations, then the model requires recalibration. In the case of grains prices, the substitution parameters of the model's demand equation are recalibrated

Agricultural productivity is difficult to observe, and so we use interannual output changes as a proxy. An alternative would be to use yields. However, in the available data sets, yields are defined as production divided by harvested area. Since harvested area is also subject to climate volatility (some planted area may not be harvested in a bad year), we view the interannual random change in production as a better measure of climate induced productivity. To determine the standard deviation of the interannual output changes, production data is obtained for three Tanzanian grains – maize, paddy rice, and sorghum – from FAOSTAT for the years 1971 to 2001 (FAO, 2010). These three crops collectively proxy for the grains sector that we use in our CGE model analysis. The interannual percentage changes are then calculated for the aggregate and tested for time trends, with none being found.

The price volatility for each aggregated crop is then determined through a more complex approach, involving data from a variety of sources for the period 1990 to 2003. The time series for the price volatility estimation is smaller than the series for the productivity volatility estimation due to the unavailability of reliable data necessary for the estimation. The three different types of data used are:

Q_{tir} – Production data in tonnes from FAOSTAT for disaggregated crop i .

P_{tir} – Price data from before 1991 in LCU/tonne from price data of Morrissey and Leyaro (2007).

D_{tr} – GDP deflator from the IMF's International Financial Statistics (IMF, 2009).

A composite real price for grains in US dollars can then be calculated following equations A1-A4:

$$\text{Real}P_{tir} = \frac{P_{tir}}{D_{tr}} \quad \text{EQ (A1)}$$

$$\text{TotalValue}_{tr} = \sum_r (\text{RealP}_{tir} * Q_{tir}) \quad \text{EQ (A2)}$$

$$\text{ValueShare}_{tir} = \frac{\text{RealP}_{tir} * Q_{tir}}{\text{TotalValue}_{tr}} \quad \text{EQ (A3)}$$

$$\text{PAggCrop}_{tr} = \sum_i (\text{ValueShare}_{tir} * \text{RealP}_{tir}) \quad \text{EQ (A4)}$$

As before, no trends were found in the price series and the price volatility is estimated as the standard deviation of the interannual percentage changes in price. However, when stochastic simulations of the estimated productivity volatility are implemented, the price volatility is found to be excessively high. In order to reduce the domestic grain price volatility in Tanzania, it is necessary to increase their own price elasticities of domestic demand for grains. This is achieved by reducing the substitution parameter for *Grains* in the model's utility function, which in turn increases the magnitude of the compensated own-price demand elasticity of grain. Once the simulated price volatility matches the estimated volatility we can be confident that the model is able to accurately delineate grains price sensitivity to productivity changes.