

Food Security for Whom?: The Effectiveness of Food Reserves in Poor Developing Countries *

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August 24, 2015

Abstract

We evaluate the optimal grain storage policy for a poor grain-importing country exposed to a highly volatile world grain price. In this country, households are heterogeneous in their income endowment, are unable to self-insure against price shocks, and suffer from hunger whenever they cannot afford to purchase adequate amounts of food. The government's objective in storing grain is to prevent spikes in the number of households suffering from hunger. Our analysis emphasizes the trade-off between raising stocks to prevent hunger tomorrow and releasing stocks to reduce hunger today. The model is calibrated to reflect food supply and demand in Haiti. Our results indicate that, rather than storing grain, Haiti would be better off if it fought poverty directly through income transfers, given that a relatively small reduction in income inequality would outperform the modest social protection that would be provided by maintaining a buffer stockpile.

Keywords: food crisis; hunger; grain reserve; Haiti. *JEL:* Q18, Q11, I38

*This research was partially funded by U.S. Department of Agriculture Office of the Chief Economist Cooperative Agreement 58-0111-14-024

1 Introduction

During the Global Food Price Crisis of 2007-2011, tens of millions of people suffered from hunger because food had become expensive. The Crisis was particularly dramatic from late 2005 to mid 2008, when world cereal prices increased by 150% (see Figure 1). Although prices subsided over the next two years, they remained highly volatile, at least when compared to price variations from 1990 to 2005.

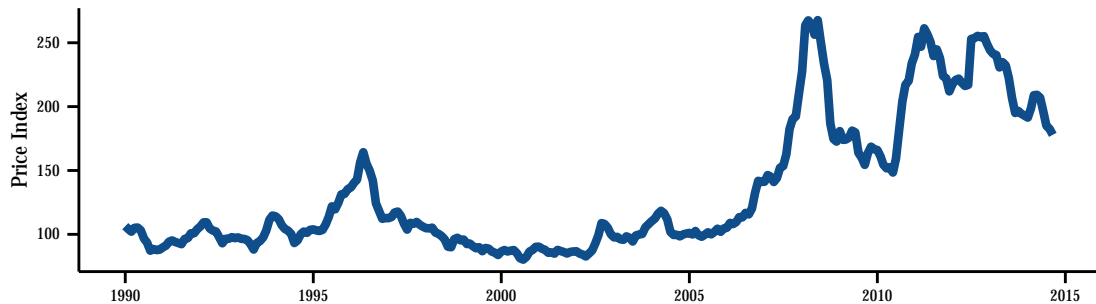


Figure 1: FAO's Cereal Price Index

In developing countries, high cereal prices are harmful to the poor because most of them are net food buyers who spend a sizable share of their income on food. Their plight is worsened by the fact that the prices of major grains —maize, rice and wheat account for 60% of the world's food energy intake (FAO 1995)—rise and fall together, preventing them from substituting an expensive staple with a cheaper alternative. Even if temporary, food price spikes can cause irreversible damage to those forced to reduce consumption, especially young children (Chilton, Chyatte, and Breaux 2007). In many countries, the threat of starvation pushed vulnerable populations into despair, resulting in social turmoil: in 2008 more than 60 food riots occurred worldwide in 30 different countries (Bellemare 2015; Lagi, Bertrand, and Bar-Yam 2011; Schneider 2008).

Anticipating that grain prices will remain highly volatile over the foreseeable future, several authors have recommended the use of public food reserves to mitigate against famine. For example, Sampson (2012) justifies public stockpiling by pointing out the inadequacy of relying on markets due to unreliable commitments by key exporters. Crola (2011) argues that local and national food reserves can play a vital role in price stabilization, provided they are operated according to predefined rules so as to reduce the political uncertainty. For Galtier (2014) in a world without storage policies,

it is very complicated to face food security issues induced by price hikes, because other policies to curb price volatility (improving food markets) or its effects (risk hedging, targeted transfers) will be ineffective.

The advice to rely more on food reserves has been followed by many policymakers. Numerous Middle Eastern, Sub-Saharan African, Asian and Caribbean countries decided to increase the size of their strategic grain reserves. Saudi Arabia, for example, committed to keeping a 6-month wheat supply on stock (McKee 2012). Another example, Haiti, in July of 2013 began construction of a storage complex with capacity for 35,000 metric tonnes of grain.

Nonetheless, there is no consensus about whether buffer stocks are a suitable solution to the volatility problem. For example, it has been argued that panic purchases from importers seeking to build up reserves combined with government-imposed export restrictions contribute to exacerbate the Crisis. As prices began to rise in 2006-2007, several grain exporting countries restricted their sales of grain in an attempt to curb food inflation in their economies. For example, India and Vietnam curtailed rice exports in late 2007. This restriction induced rice importers –most notably the Philippines–to purchase massive amounts of rice in early 2008 as a safeguard against prolonged trade disruptions. However, the increased demand pushed the price of rice even higher, prompting a new wave of export restrictions by Vietnam, Cambodia, and Egypt. The situation was similar in the wheat market. Following a poor harvest in Australia, wheat prices rose 32% during 2005-06. In response, Ukraine imposed export quotas in late 2006, followed by a complete ban in July 2007, forcing its usual clients to buy wheat from Argentina, the U.S., Kazakhstan and Russia. Argentina raised its wheat export tax in November 2007, while Kazakhstan and Russia restricted exports in early 2008, as their stocks were plummeting. Meanwhile, U.S. wheat exports surged, mainly because of increased demand from Egypt. As pressure on American exports rose, the price of wheat kept increasing, reaching US\$440 per tonne in March 2008, 115% above the December 2006 level.¹

The renewed interest in the use of public food reserves has motivated work on the optimal implementation of such policy. Notable examples are Gouel and Jean (2012), who analyze the optimal combination of storage and trade policy in a small, open developing country; and Gouel (2013), who finds very low welfare gains from implementing an optimal food price stabilization policy in a self-sufficient developing country. The low welfare gains are the consequence of public storage crowding out private storage by removing any profit opportunity from speculation, a result

¹For a detailed discussion of the several causes of the Crisis, see Headey and Fan (2008) and Headey and Fan (2010).

consistent with earlier work by Miranda and Helmberger (1988).

This paper contributes to the emerging literature on optimal storage policy by using a different definition of *optimality*. Unlike previous work, where the optimal reserve operation is defined in terms of a social surplus, we focus on the reserves ability to mitigate spikes in the country's *hunger rate*. After all, the main concern about the Food Crisis is its effect on hunger among the poor. Our model offers a simple way to quantify how variations in global grain prices affect the hunger rate, which ultimately depends on the share of imported grain in household budgets and the income distribution. Thus, a second distinctive feature of our model is that households are heterogeneous in their income endowments.

In the model, to prevent hunger during times of high prices, the government sells grain from its reserve and uses the revenue to subsidize grain imports. In turn, during tranquil periods, the government accumulates grain, financing its purchases by charging a tariff on grain imports. The model thus captures an essential trade-off in implementing a buffer stock policy: raising a stock to prevent hunger tomorrow requires resources that could be used to reduce hunger today. For a poor developing country this trade-off is not trivial, as many people suffer from hunger even when food is inexpensive.

Since the model lacks a closed-form solution, it is solved numerically using orthogonal collocation methods. Its parameters are calibrated to reflect food supply and demand in Haiti, where grain imports account for one-third of the food budget. We simulate a food crisis by introducing an 85% increase in the price of grain, which roughly corresponds to the variation in the price index of Haiti's cereal imports during the Global Crisis.

We find that most of the time the storage policy, whether of grain or cash, would fail at avoiding hunger during a crisis, because the reserve is below the optimal level due to having been depleted in previous crises. More importantly, the results suggest that rather than storing food (or cash), a better approach for a poor country is to fight poverty directly through direct cash transfers, since the modest social protection provided by a storage policy could be obtained at a lower cost through relatively small improvements in per capita income and reductions in income inequality.

The rest of the paper is organized as follows. In Section 2, we develop a model of the food market in a poor, grain-importing country. The government's problem is formulated as a Bellman equation, which we solve by numerical methods in Section 3. Results are presented in Section 4. Section 5 concludes.

2 The model

Consider a grain importing country with population 1, inhabited by a continuum of households indexed by $i \in I := [0, 1]$. Households have identical preferences but different incomes, and do not have access to financial services (no deposits, credit, or insurance). Households prepare their food by combining an imported grain and a local “vegetable. Since all grain is imported, the households’ nominal incomes do not depend on the price of grain, and we can analyze the effect of the crisis on consumers alone.

Because of fluctuations in the international price of grain and lack of financial services, the country’s hunger rate is also volatile. The government wants to prevent spikes in the hunger rate by operating a grain reserve. Its problem can be formulated as a Bellman equation, once we describe the demand for food, the distributions of income and food consumption, and the dynamics of grain prices.

2.1 The demand for food

Household utility depends on the consumption of two final goods: food and a non-edible good (the numeraire). Households prepare their *food* at home by combining two *ingredients*, an imported grain and a domestic vegetable, according to a CES recipe:

$$f(x_g, x_v) = \left(\theta^{\frac{1}{\sigma}} x_g^{\frac{\sigma-1}{\sigma}} + (1-\theta)^{\frac{1}{\sigma}} x_v^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad (1)$$

Here, f is the amount of food prepared by combining x_g units of grain and x_v units of vegetable, θ is the relative importance of the grain in the recipe, and σ is the elasticity of substitution, which reflects the households’ willingness to substitute ingredients in response to changes in their relative price.

The international price of grain is p_g^* , which is imported subject to a tariff rate τ . There are no transportation or retailing costs, so the consumer price of grain is $p_g = (1 + \tau)p_g^*$. On the other hand, the price of the domestic vegetable is p_v .

Household i has a food budget M_i to spend on the two ingredients. Given this budget, the

household problem is to maximize the amount of food consumed:

$$\max_{x_g, x_v} f(x_g, x_v)$$

subject to the cost of ingredients to be within budget

$$p_g x_g + p_v x_v \leq M_i$$

Solving this problem, household i buys

$$\hat{x}_g = \theta \left(\frac{P}{p_g} \right)^\sigma \frac{M_i}{P}, \quad \hat{x}_v = (1 - \theta) \left(\frac{P}{p_v} \right)^\sigma \frac{M_i}{P} \quad (3)$$

units of grain and vegetables, respectively, which allows it to prepare and consume

$$f_i(\hat{x}_g, \hat{x}_v) = \frac{M_i}{P} \quad (4)$$

units of food. In (3) and (4), P is an aggregate price that adjusts for the substitution between the two ingredients:

$$\begin{aligned} P &\equiv P(\tau, p_g^*, p_v) \\ &= \left\{ \theta [(1 + \tau) p_g^*]^{1-\sigma} + (1 - \theta) p_v^{1-\sigma} \right\}^{\frac{1}{1-\sigma}} \end{aligned} \quad (5)$$

Since the solution satisfies

$$P(p_g, p_v) f(\hat{x}_g, \hat{x}_v) = M = p_g x_g + p_v x_v,$$

one can think of P as the effective price of food, and (5) quantifies the impact of an increase on the international price of the staple grain on the domestic food price index (the *pass-through*, for short). In what follows we assume that p_v is constant and, to simplify notation, the dependence of the food price index P on the price of vegetables p_v will be implicit.

The next step in determining the amount of food consumed by household i is to specify how much it spends on food, M_i . Assume that the income elasticity η and the price elasticity α of the demand for food f_i^d are constant, that is, $f_i^d = \zeta P^{-\alpha} y_i^\eta$, where ζ is a scale parameter, and y_i is household

i 's income. Then household i spends $M_i = \zeta P^{1-\alpha} y_i^\eta$ on ingredients, and food consumption is given by (substitute on (4))

$$\begin{aligned} f_i(\hat{x}_g, \hat{x}_v) &= \frac{\zeta P^{1-\alpha} y_i^\eta}{P} \\ &= \zeta P(\tau, p_g^*)^{-\alpha} y_i^\eta \\ &\equiv f(y_i, \tau, p_g^*) \end{aligned} \tag{6}$$

Therefore, the amount of food consumed by household i ultimately depends on its income, the tariff rate, and the international price of grain.

2.2 The distributions of income and of food consumption

Household i is endowed with income y_i every period. The distribution of income across the population is described by a log-logistic, or Fisk, distribution (Fisk 1961):

$$\begin{aligned} F_y(y|a_y, b_y) &= \mathbb{P}(y_i \leq y) \\ &= \left[1 + \left(\frac{y}{a_y} \right)^{-b_y} \right]^{-1}, \quad (y \geq 0) \end{aligned} \tag{7}$$

where $a_y > 0$ and $b_y > 1$ are the scale and shape parameters, respectively, and $\mathbb{P}(\mathcal{A})$ denotes the probability of an event \mathcal{A} . Define the functional $\mathbb{S}(g)$ as the sum of $g_i \equiv g(y_i)$ for all households, that is $\mathbb{S}(g) \equiv \int_I g(y_i) dF_y$. The income distribution implies that per-capita income is²

$$Y = \mathbb{S}(y_i) = a_y \frac{\pi/b_y}{\sin(\pi/b_y)}$$

and the Gini coefficient is $G = \frac{1}{b_y}$ (Kleiber and Kotz 2003, p. 224). Given (6) and (7), food consumption has the Fisk distribution³ $F_{\text{food}} \sim \text{Fisk}(a_f P^{-\alpha}, b_f)$, where $a_f = \zeta a_y^\eta$ and $b_f = \frac{b_y}{\eta}$.

2.3 Measuring hunger

A household that consumes less than c units of food in a period is considered hungry or undernourished. The *hunger rate* Γ is defined as the share of the population who is hungry, and is given

²Notice that per-capita income equals aggregate income, because population is one.

³One useful property of the Fisk distribution is that if $x \sim \text{Fisk}(a, b)$, then $kx^\gamma \sim \text{Fisk}(ka^\gamma, b/\gamma)$.

by

$$\begin{aligned}
\Gamma(P) &= F_{\text{food}}(c | a_f P^{-\alpha}, b_f) \\
&= \left[1 + \left(\frac{c P^\alpha}{a_f} \right)^{-b_f} \right]^{-1} \\
&= \left[1 + \left(\frac{c P^\alpha (G\pi)^\eta}{\zeta Y^\eta \sin^\eta(G\pi)} \right)^{1/G\eta} \right]^{-1}
\end{aligned} \tag{8}$$

That is, the hunger rate of the country depends on its per capita income Y , income inequality G , and the price of food P . In what follows, we assume that the income level and distribution are constant, to focus on the effects of the international price of grain and the import tariff on hunger.

2.4 The dynamics of grain prices

The international price of grain follows a discrete Markov process with two states: in a *tranquil* period $p_g^* = p_L$, while during a *food crisis* $p_g^* = p_H$, where $p_L < p_H$. The transition between tranquil periods and food crises depends on the probabilities $\pi_{jj'} = \mathbb{P}(p_{g,t} = p_{j'} | p_{g,t-1} = p_j)$, where $j, j' \in \{L, H\}$.

Equation (8) quantifies the effect of a food crisis on the incidence of hunger in the country. An increase in the price of imported grain raises the domestic food price index, inducing a reduction in food consumption and pushing some of the households into hunger. This is illustrated in Figure 2, which plots the density function of food consumption for two alternative grain prices. In the figure, households with food consumption below the hunger threshold suffer from hunger; region **B** represents the share of the population that is lead into hunger as the price of grain increases. In the absence of a policy intervention (that is, $\tau = 0$), the hunger rate simply sticks to the price process, switching between $\mathbf{A} = \Gamma(P(0, p_L, p_v))$ and $\mathbf{A} + \mathbf{B} = \Gamma(P(0, p_H, p_v))$.

2.5 The government's problem

The government of the country is concerned with the potential episodes of extreme hunger ($\mathbf{A} + \mathbf{B}$ in Figure 2) that result from a price hike in the grain market. This is formalized by setting the

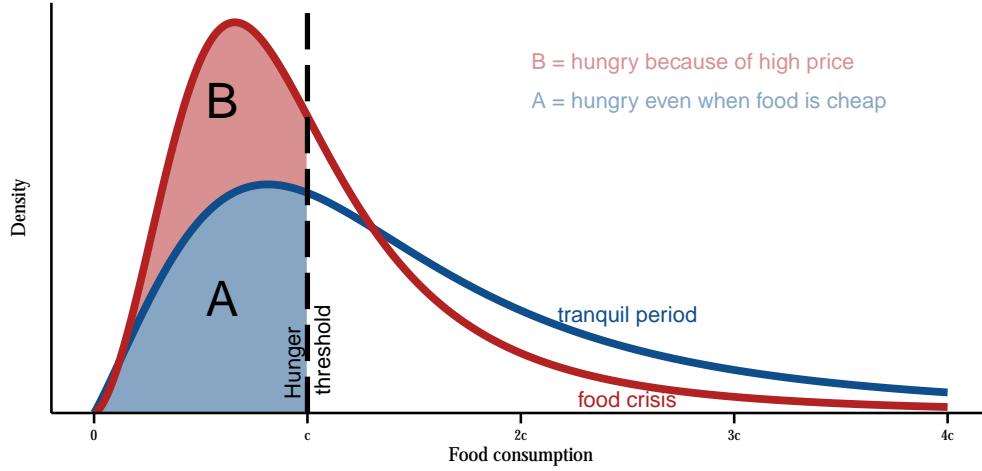


Figure 2: Food Consumption Density

Hunger occurs when food consumption is below c . When $p_g^* = p_L$ the hunger rate is **A**; a price increase shifts the distribution to the left, dragging a proportion **B** of the population into hunger.

government's one-period utility or reward function as

$$r_H(\tau, p_g^*) = \begin{cases} \frac{1}{1-\rho} [1 - \Gamma(\tau, p_g^*)]^{1-\rho}; & \text{if } \rho \neq 1 \\ \log[1 - \Gamma(\tau, p_g^*)], & \text{otherwise} \end{cases}$$

where ρ is the government's relative risk aversion.

To avoid extreme hunger, the government operates a grain reserve as follows. During tranquil periods, the government uses the fiscal revenue Υ from the import tariff to buy and accumulate grain. During a crisis, the government eliminates the tariff and instead subsidizes grain imports; the subsidy is financed by selling all or part of the stock available at the beginning of the crisis. Thus, the size of the grain reserves s_t evolves according to:

$$s' = (1 - \phi) \left[s + \frac{1}{p_g^*} \Upsilon(\tau, p_g^*) \right] \quad (9)$$

where ϕ is the cost of storing one unit of grain per period and the prime symbol indicates next

period variables. The physical grain stock cannot be negative. The fiscal revenue is

$$\Upsilon(\tau, p_g^*) = \tau p_g^* \hat{x}_g = \tau p_g^* \theta [(1 + \tau)p_g^*]^{-\sigma} \zeta P(\tau, p_g^*)^{\sigma - \alpha} \mathbb{S}(y^\eta)$$

The government cares for present and future hunger, so let us define its value function by

$$V(s_t, p_{gt}) = \max_{\tau} \mathbb{E}_0 \sum_{t=0}^{\infty} \delta^t r_H(\tau_t, p_{gt}^*)$$

where $\delta \in (0, 1)$ is a discount factor. Since this problem is recursive, it can be written in terms of the following Bellman equation

Policy case A:

$$V(s, p_g^*) = \max_{\tau, s'} \{r_H(\tau, p_g^*) + \delta \mathbb{E}_t V(s', p_g^{*'})\} \quad (10)$$

subject to resource constraint (9) and to $s' \geq 0$.

We next consider three variations to the government problem. In the first variation, the government accumulates bank deposits instead of grain, because it lacks storage facilities. (Policy B). In the other two variations, the grain reserve is operated not to minimize hunger explicitly, but to maximize consumers welfare (Policy C) or to fix the domestic price of grain (Policy D).

Financial reserve

The government could simply set a *financial* reserve. Assuming that it can buy bonds or deposits D that yield a risk-free interest rate r , the resource constraint becomes

$$D' = (1 + r) [D + \Upsilon(\tau, p_g^*)] \quad (11)$$

and its corresponding Bellman equation is

$$V(D, p_g^*) = \max_{\tau, D'} \{r_H(\tau, p_g^*) + \delta \mathbb{E}_t V(D', p_g^{*'})\}. \quad (12)$$

subject to accumulation of deposits in (11) and to $D' \geq 0$ (credit not available).

Maximizing welfare

For a household with food demand (6), the associated indirect utility is

$$v_i = v(y_i, \tau, p_g^*) = \frac{y_i^{1-\eta}}{1-\eta} - \zeta \frac{P(\tau, p_g^*)^{1-\alpha}}{1-\alpha}.$$

Integrating v_i over the income distribution, the one-period social welfare is

$$W(P) \equiv \mathbb{S}(v) = \frac{1}{1-\eta} \mathbb{S}(y^{1-\eta}) - \zeta \frac{P(\tau, p_g^*)^{1-\alpha}}{1-\alpha}$$

In this case, the Bellman equation is similar to (10) but with the following one-period reward function:

$$r_W(\tau, p_g^*) = \begin{cases} \frac{1}{1-\rho} \mathbb{S}[v(\tau, p_g^*)]^{1-\rho}; & \text{if } \rho \neq 1 \\ \log \mathbb{S}[v(\tau, p_g^*)], & \text{otherwise} \end{cases}$$

Fixing the price of grain

Alternatively, the government attempts to fix the domestic price of grain at its stationary mean $\bar{p}_g = \pi_L^* p_L + \pi_H^* p_H$, where the stationary distribution of the international price of grain is

$$\pi_L^* = \frac{\pi_{HL}}{\pi_{LH} + \pi_{HL}} \qquad \pi_H^* = \frac{\pi_{LH}}{\pi_{LH} + \pi_{HL}}$$

To this end, the government sets the tariff rate at $\pi_H^* \frac{P_H - P_L}{P_L}$ when grain is inexpensive⁴. During a crisis, grain imports are subsidized at a rate of $\pi_L^* \frac{P_H - P_L}{P_H}$ as long as there is enough grain in storage; when storage is binding, there will be a stock-out and the subsidy rate is the root of equation (9).

3 Solving the model

We now describe the numerical methods employed to solve the model, as well as the calibration of parameters to the supply and demand conditions in Haiti.

⁴Here we assume that the government has unlimited storage capacity

3.1 Food storage in Haiti

The World Food Price Crisis hit Haiti especially hard. Being the poorest country in the Western Hemisphere, hunger was widespread among its population even *before* the crisis. In 2005 half of the population suffered undernourishment (WorldDatabank). Furthermore, the country is highly dependent on food imports: in 2007, nearly 70% of the cereals consumed were imported, and imports accounted for 56% of the calorie intake of the population (FAO Food Balance Sheet).

As the World Food Crisis developed, food prices spiked in Haiti. The price of rice nearly doubled between December 2007 and April 2008. Tensions exploded on April 2 in Okay, where demonstrators clashed with United Nations peacekeepers. Over the following days, in Port-au-Prince, thousands of protesters set up flaming barricades and threw rocks at the national palace, burned gas stations and looted businesses (Lindsay 2008). On April 12, the government of Prime Minister Jacques Edouard Alexis was ousted by senators, while President Rene Preval responded to the social unrest by promising to support local farmers and reduce the price of a 110-pound sack of rice from \$51 to \$43 (Delva and Loney 2008).

In the aftermath of the Crisis, in July of 2013, the government of Haiti began the construction of a strategic reserve to store food in Lafiteau, about nine miles north of Port-au-Prince. The storage complex consists of four silos and a shed, with a combined capacity of 35,000 metric tons. In words of Prime Minister Lamothe,

The construction of this strategic reserve reflects the desire of my Government to promote national agricultural production, stabilize the market price of commodities and combat food insecurity. Indeed, the fight against hunger and extreme poverty constitutes the main pillars of government action. (Primature, Rpublique d’Hati 2013)

In what follows, we evaluate to what extent this new strategic reserve might succeed in stabilizing the price of food and averting extreme hunger in Haiti. For simplicity, we assume that the reserve stores only imported grain. Hence, we do not address other potential benefits of the reserve, such as increasing the supply of domestic food by giving farmers the necessary facilities to store part of their crops. This benefit is not trivial, since each year Haiti’s farmers lose between 30% and 40% of their crops due to lack of storage space (*ibid.*).

Parameter	Value	Description
α	0.788	price elasticity food demand
η	0.814	income elasticity food demand
σ	0.500	elasticity of substitution
θ	0.333	share of grain in food budget
c	30.258	hunger threshold
ζ	1.208	food demand scale
Y	114.925	income per capita
G	0.590	Gini coefficient
p_L	1.000	price of grain when low
p_H	1.850	price of grain when high
p_v	1.000	price of vegetable
γ	0.200	proportion of years in crisis
ψ	3.000	expected duration of food crisis
δ	0.970	government discount factor
ρ	2.500	government relative risk aversion
ϕ	0.025	marginal cost of storage
r	0.010	interest rate

Table 1: Parameters for baseline scenario

3.2 Parameter calibration

We calibrate the parameters of the model to anticipate the performance of a grain storage policy in Haiti. The time unit is a quarter of a year. The baseline values, shown in Table 1, were chosen as follows.

Income per capita in 2012 was US\$459.7 (real, 2005 base), or $Y = 114.9$ dollars per quarter. The Gini coefficient was $G = 0.59$ in 2001 (WDI). We did not find estimates for the income- and price elasticities of food demand in Haiti, so we set these parameters to the average elasticities from countries⁵ where income per capita is similar to Haiti's. The estimated elasticities for those countries are drawn from Muhammad et al. (2011).

To determine the importance of food expenditure in household budgets, we estimate a linear regression of the consumer price index on its component indices (prices of food, clothing, rent, housing, health, transportation, education, and other) with monthly data for June 2004 to June 2013. Since all these indices have a common base, we normalize prices to one during a tranquil quarter, that is $p_L = p_v = 1$. From the regression, we found that households spend nearly half of their income on food; this result is replicated in the model for a tranquil quarter by setting the demand scale to $\zeta = 1.21$.

⁵The list includes Ethiopia, Guinea, Guinea-Bissau, Mali, Rwanda, Sierra Leone, Togo, and Uganda.

Having calibrated the demand for food and the income distribution, we used the resulting food consumption distribution to set the value of the hunger threshold at $c = 30.26$, which implies a hunger rate of 44.5% in a normal year. This hunger rate coincides with Haiti’s undernourishment rate for 2011 (WDI).

We assume that the two ingredients are relative complements ($\sigma = 0.5$). To set the weight of grain in the recipe (1), we applied two different procedures. In the first procedure, we used FAO’s Food Balance Sheets from 2006 to 2009 to determine the proportion of the supply of calories that is accounted for by imports of wheat, rice and maize. In the second procedure, we estimated a linear regression of the food price index on its local and imported components. In the two procedures the weight of the imported food was close to $\theta = 1/3$.

The price of grain during a crisis was computed as follows. With monthly data on the international prices for wheat, maize and rice for January 1960 to August 2013 (GEM Commodities), we computed a grain price index for Haiti, using the volume of imports for 2006 to 2009 as weights. We deflated this index with the CPI of the United States and then decomposed the resulting (log) real price index into a trend and a cyclical component using the Hodrick-Prescott filter. During the Food Price Crisis, the real price of imported grain reached a peak of 85% deviation over its trend value; thus in the model $p_H = 1.85$.

We assume that crises occur in one out of five quarters ($\gamma = 0.2$), and that they typically last $\psi = 3$ quarters. For a two-state Markov process, these two assumptions imply that the probability of having a crisis next period is $\pi_{HH} = 2/3$ if currently in crisis, and $\pi_{LH} = 1/12$ otherwise.

We also assume a discount factor of $\delta = 0.97$, the cost of storing food at $\phi = 0.025$ per unit of grain, and the interest rate of $r = 1\%$. All these values are quarterly. Finally, we set the government’s risk aversion to $\rho = 2.5$.

In order to determine how sensitive the optimal storage policy and the hunger rate are to some of the key parameters, we consider four variations to the baseline (Scenario 1) from Table 1. In Scenario 2, the government is more risk averse ($\rho = 3$). In Scenario 3, crisis are expected to be longer ($\psi = 4$). In Scenario 4, the cost of storage is higher ($\phi = 0.05$). Finally, in Scenario 5, a food crisis is less severe ($p_H = 1.6$).

3.3 Numerical methods

Once the baseline parameters were chosen, we solved the Bellman equations (10) and (12) using collocation methods. The numerical work was implemented in MATLAB, using the *CompEcon* toolbox available from Miranda and Fackler (2002). In particular, the value functions in (10) and (12) were each approximated as the sum of twelve Chebyshev polynomials, using the corresponding Chebyshev nodes for the continuous state variable s_t , and for discrete state reflecting the prices $p_g \in \{1.00, 1.85\}$. The model was solved using the *dpsolve* solver from CompEcon. Figure A3 plots the residuals for all scenarios and for policy cases A to C.⁶

Once the model was solved, we implemented a Monte Carlo simulation of the tariff rules with 10^5 replications, to compute the long-term distribution of the reserve holdings and of the hunger rate for each scenario-policy combination.

3.4 Euler equation

We can get some insight into the optimal stockpile policy from inspecting the Euler equation. In Bellman equations (10) and (12) there are two policy variables (the tax rate and the ending stock) related by the resource constraints (either 9 or 11). While in the numerical solution to the problem it is convenient to substitute the ending stock and use the tax rate as the only policy variable, in this section we obtain an Euler equation by implicitly using ending stock as the policy variable. Assuming that the non-negativity constrain on ending stock is not binding⁷, the Euler equation for government problems (10) and (12) is

$$1 = \mathbb{E}_t \left[\delta \left(\frac{1 - \Gamma'}{1 - \Gamma} \right)^{-\rho} \frac{\Delta \Gamma' \Delta \Upsilon}{\Delta \Gamma \Delta \Upsilon'} R \right]$$

where the Δ operator indicates differentiation with respect to the tax rate, the prime indicates next-period variables, and R is the return of investing one unit of numeraire in ending stock:

$$R = \begin{cases} (1 - \phi) \frac{p_{g,t+1}^*}{p_{g,t}^*} & \text{for grain stock;} \\ 1 + r & \text{for deposit.} \end{cases}$$

⁶We also solved a version of the model where the government uses a financial reserve to maximize welfare; the results are omitted because in all scenarios it is optimal to not intervene.

⁷This is the case for tranquil periods in all scenarios discussed in the Results section.

Variable	Scenarios 1 to 4			Scenario 5		
	p_L	p_H	$\Delta\%$	p_L	p_H	$\Delta\%$
P	1.00	1.25	25.5	1.00	1.18	18.4
$\mathbb{S}(f)$	50.86	42.54	-16.4	50.86	44.51	-12.5
$\mathbb{S}(x_g)$	16.95	11.68	-31.1	16.95	12.76	-24.7
$\mathbb{S}(x_v)$	33.91	31.76	-6.3	33.91	32.29	-4.8
$\mathbb{S}(w_g)$	0.33	0.40	21.4	0.33	0.39	16.2
P^c/Y	0.26	0.33	25.5	0.26	0.31	18.4
Γ	0.44	0.54	20.8	0.44	0.51	15.5

Note: The variables are food price index P ; per capita consumption of food $\mathbb{S}(f_i)$, grain $\mathbb{S}(x_{gi})$ and vegetable $\mathbb{S}(x_{vi})$; share of grain in food budget $\mathbb{S}(w_{gi})$; share of critical food on national income P^c/Y ; and hunger rate Γ .

Table 2: No Policy: Results for All Scenarios

Since the price of grain fluctuates, investing in grain is risky. In particular, the expected return on grain bought during a tranquil period is

$$\mathbb{E}[R] = (1 - \phi) \left[1 + \pi_{LH} \left(\frac{p_H}{p_L} - 1 \right) \right]$$

i.e. the return is simply the expected capital gain, adjusted for storage cost. Notice that this capital gain is positively correlated with hunger: when the price of grain increases, both the capital gain and the hunger rate increase too.

4 Results

During a food crisis, the international price of grain increases by 85%. Without any policy intervention (see Table 2), the crisis leads to a 25% increase in the domestic price of food. The average household reduces its purchases of grain and vegetables by 31% and 6%, respectively. With less ingredients available, the household then reduces food consumption by 16%. Ultimately, the number of households suffering from hunger increases by 21%. These results are common to all scenarios except for Scenario 5, which assumes a less severe increase in the price of grain (60%), thus resulting in a smaller increase in the hunger rate (15%). Notice that in the worst situation, the cost of providing just enough food c to each household is equivalent to 33% of national income.

The pass-through coefficient is 0.3, which is not significantly smaller than the weight of grain in the food budget (0.33). This follows from assuming that the ingredients are complements.

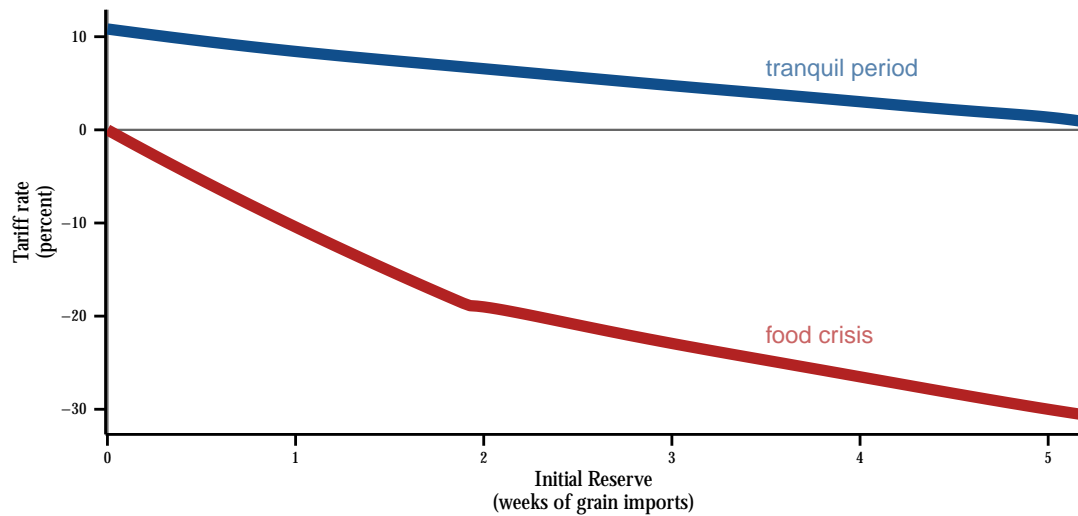


Figure 3: Optimal Tax Rate

When grain is cheap, the government collects tariff revenues to buy and store grain. During a food crisis, it sells grain and transfers the subsidy to households.

4.1 Baseline model

The results in this section refer to the *baseline model*, which consists of policy case A with parameters from Scenario 1. First, we describe the optimal policy rule. We then analyze the long-term potential of the reserve to alleviate hunger.

The optimal policy rules

The optimal stockpiling policy can be described in terms of the tariff rate, the size of the grain reserve, or the actual hunger rate. Figure 3 presents the optimal tariff rate as a function of the initial stock of grain and its international price. As expected, the tariff is always negative during a crisis, as the government sells grain from its stock to subsidize grain imports. In a tranquil period, the tariff rate is positive whenever the initial reserve is below its full capacity of 5.1 weeks of grain. The tariff rate is decreasing with respect to the initial stock both during crisis and tranquil quarters. However, the range of the optimal tariff rate is asymmetric around zero: in a tranquil period the maximum rate is set at 10.8% (when the reserve is empty), while during a crisis the maximum subsidy rate is 30.5% (when the reserve is full).

In terms of the numeraire, the tariff range implies that the domestic price of grain varies between

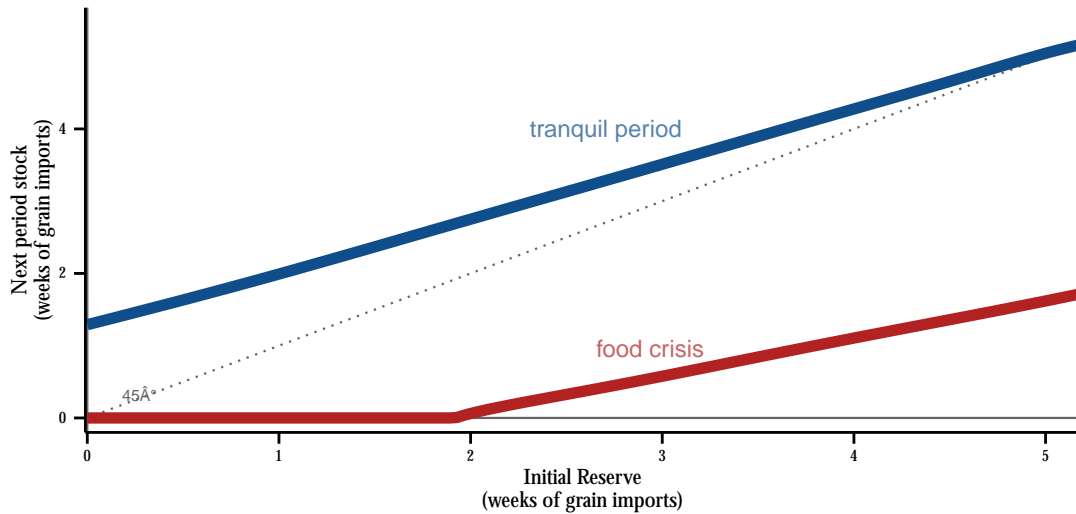


Figure 4: Optimal Food Storage

The maximum stockpile covers 5.1 weeks of grain imports. The country accumulates grain when it is cheap, to release it during crises.

1.01 and 1.11 during tranquil periods and between 1.29 and 1.85 during a crisis. Clearly, the grain reserve would be ineffective at eliminating the variability of the food price, although in the best case (when the reserve is full) it would dampen the increase in the price of food, from 25% (no policy) to 9%.

Together with the transition equation (9), the tariff policy implicitly defines the optimal storage rule depicted in Figure 4. Starting with an empty reserve in a tranquil period, the government would use its fiscal revenue to accumulate 1.3 weeks of grain. As long as the price of grain remains low, the government would acquire additional grain, although at a slower pace because the optimal tariff revenue is decreasing on the initial stock. If no crisis occurs, the government would take two years to restock 90% of the stock capacity. Once the reserve is full, the tariff rate is set at 1.0% to cover the cost of maintaining the stock.

In contrast to the long time necessary to replenish the reserve during tranquil periods, a full reserve would be depleted in just two quarters if a crisis hits the country. Initially, the government would sell two-thirds of its stock at the beginning of the crisis. If the crisis persists for an additional quarter (which happens with probability 0.67), then the government would sell its remaining stock.

Similarly, the tariff rule implicitly defines the optimal hunger rate shown in Figure 5: the level

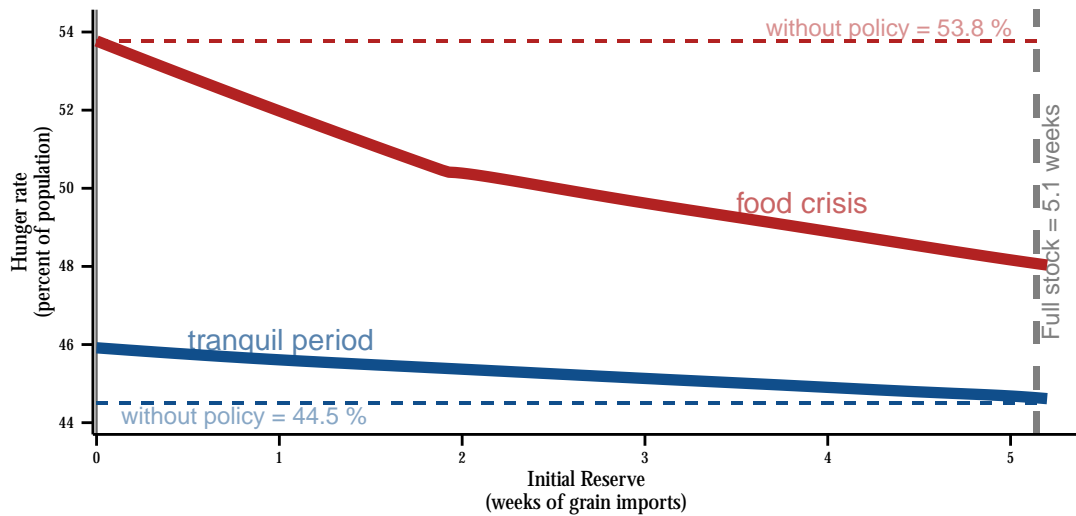


Figure 5: Hunger Rate Implied by Optimal Policy

With a full reserve of 5.1 weeks, Haiti could reduce the hunger rate during a crisis, from 53.8% to 48.1%. The downside: once the stock is depleted, restocking increases hunger from 44.5% to 45.9% during a tranquil period.

of the tariff affects the price of food (equation 5), which in turn affects the hunger rate (8). When the country faces a crisis with a full reserve, the governments grain subsidy ameliorates the drop in food consumption, resulting in a hunger rate of 48.1%. This is an improvement with respect to policy case E (do not intervene): without subsidies, the hunger rate would reach 53.8% instead. Therefore, when the reserve is full, the *benefit* of storing grain is a reduction of 5.7 percentage points in hunger during a crisis. As expected, this benefit is smaller if the size of the stock decreases, and it disappears once the reserve is depleted.

Figure 5 also illustrates the *cost* of storing grain: immediately after a stock depletion, the fiscal effort to rebuild the stock requires setting the tax rate at 10.8%. Doing so results in a hunger rate of 45.9%, compared to 44.5% that would prevail in the absence of policy intervention. That is, the cost of rebuilding the stock is 1.4 percentage points of increased hunger in a tranquil quarter. This cost declines as the stock reaches its full capacity, but it is never zero. Once the reserve is full, covering its operating cost (stock depreciation) implies a hunger rate of 44.64% —14 basis points above the no-policy rate.

As mentioned earlier, the reserve is unable to stabilize the price of food fully. Consequently, the reserve is also unable to prevent extreme hunger. Depending on the initial grain stock at the outset

of a crisis, the hunger rate will range between 48.1% and 53.8%, well above the non-crisis rate of 44.5%.

The reserve in the long-run

Analyzing the implications of the optimal taxation-storage rules in terms of the hunger rate allows to clarify the trade-offs inherent in maintaining a grain reserve: the government increases the hunger rate between 0.1 and 1.4 percentage points during tranquil quarters, in exchange for a reduction of up to 5.7 percentage points during a crisis period. Although the potential benefit far surpasses the potential cost, it should be noted that in the long run the cost is incurred four times more often than the benefit is enjoyed.

Since the actual cost and benefit of implementing the policy depend on the amount of grain available at the beginning of each period, the long-term net benefit of the government's intervention depends on the joint distribution of the reserve size and the price of grain. Figure 6 shows the cumulative distribution of the initial grain stock conditional on the two price states.

For example, because the stock is depleted in just two periods during a crisis, a subsequent period of high grain price would be faced without any grain in reserve. It would be impossible for the government to alleviate hunger in such a context. This is an important limitation of a grain stockpiling policy, as the mean duration of food crises is three quarters. In fact, over time the country would face nearly one-half of the crisis periods with an empty reserve (see Figure 6), while in only one-fifth of those episodes the reserve will be above 90% of its capacity.

The inability of the grain reserve to prevent extreme hunger is best illustrated in Figure 7, which shows a histogram of the simulated hunger rates, conditional on price. In around 72% of food-crisis periods, more than one-half of households would still suffer hunger, and in nearly 50% of crisis periods the policy would not make any difference whatsoever, as the grain reserve would be empty. On the other hand, there would be little variation in the hunger rate during tranquil times: 90% of the time it would fall between 44.6% and 45.5%.

4.2 Alternative scenarios

Table 3 summarizes the simulations of policy A for all five scenarios. Scenario 2 evaluates the effect of increasing the coefficient of relative risk aversion from 2.5 to 3.0. As expected, a more risk-averse government would be more determined to avoid extreme hunger. On average, it would keep a 16%

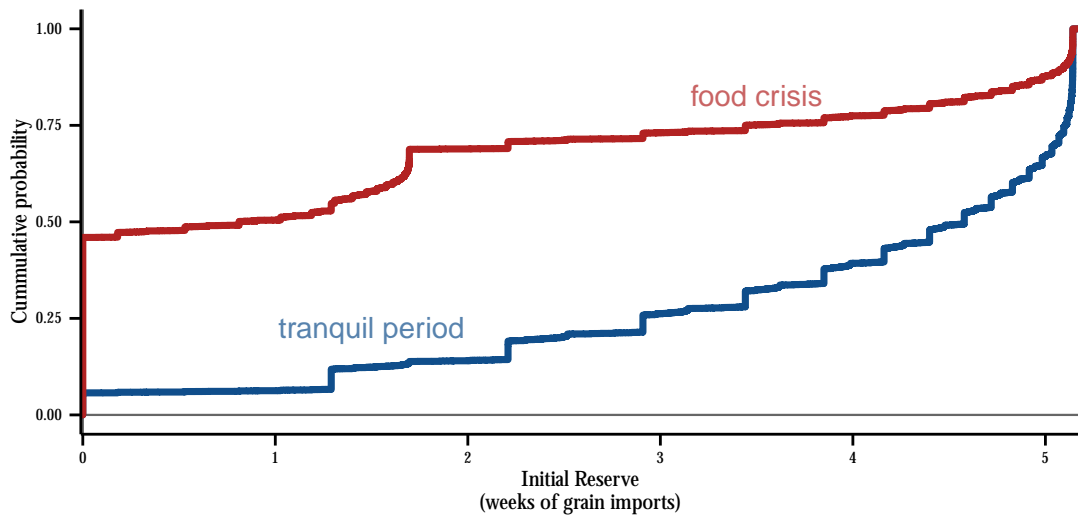


Figure 6: Size of Initial Stock in a Food Crisis (cdf)

The reserve would be empty in half of the crises. Only in one-fifth of crises the reserve would be higher than 90% of capacity.

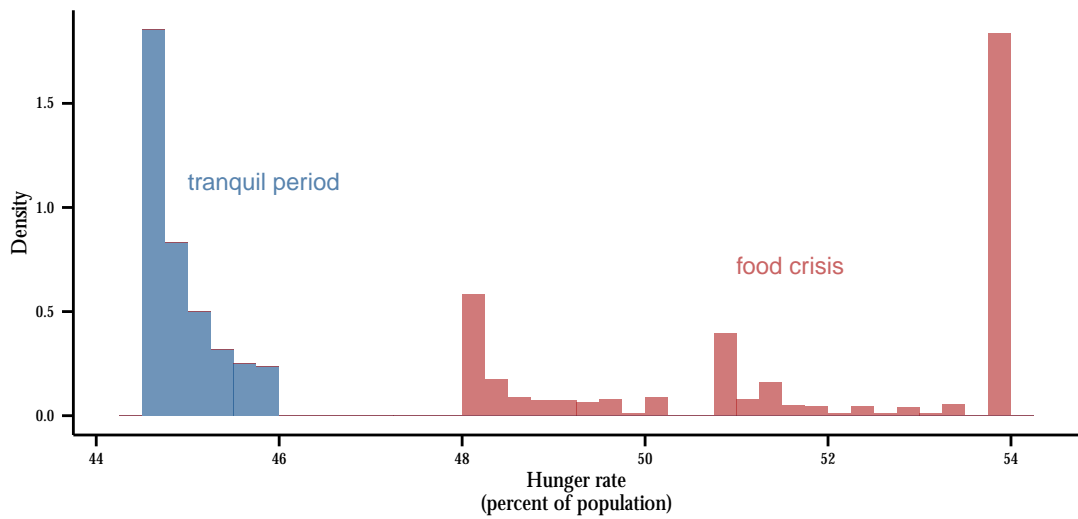


Figure 7: Distribution of Hunger, conditional on price state

Without intervention, the hunger rate would be 53.8% during crises. With intervention, hunger is below 50.0% in only one-quarter of those crises.

larger grain stock, with a maximum stock of 6.1 weeks, one week more than in the baseline. This larger reserve would allow the government to afford a 129 basis points higher subsidy in times of crisis, yet it would also require a higher tariff in tranquil periods. Despite the additional effort, the government would not succeed in avoiding extreme hunger. In nearly two-fifths of crisis periods the reserve would be empty. The average hunger rate would drop by only 0.25 percentage points during crises, while it would increase by 0.06 percentage points in tranquil periods.

When crises are expected to last longer (four quarters instead of three, Scenario 3), the optimal policy is to store 27% *less* grain. With a smaller reserve, hunger is on average 52.5% during crises, almost one percentage point above baseline. Although counterintuitive, storing less grain in this scenario follows from assuming that the share of periods in crisis remains at $\gamma = 0.2$: if the expected duration of a crisis increases from 3 to 4 quarters, then the expected duration of a tranquil period increases from 12 to 16 quarters. For a tranquil period, this reduces not only the probability of having a crisis the following quarter, but also the expected return of holding grain (equation 3.4) from 4.4% to 2.7% (quarterly).

According to Wright and Cafiero (2011), while the marginal cost of storing grain is usually modest in regions where humidity is low, modern infrastructure is available, and deterioration unimportant, this may not be the case in hot and humid regions —like Haiti. In Scenario 4 we find that the optimal storage policy is very sensitive to the cost of storing grain: if the unit cost of storage per quarter is 5% instead of 2.5%, then the maximum optimal stock is only 2.2 weeks, less than half the amount in the baseline.

The optimal storage policy is also very sensitive to the severity of a crisis. Scenario 5 assumes that the price of grain increases by 60% during a crisis (as compared to 85% in the baseline). With a smaller increase in prices, the hunger rate would reach 51.4% during a crisis. Despite facing a less threatening crisis, which would allow to reduce hunger even more with a given stock of grain, the optimal policy in this case is to have a maximum reserve of only 1.9 weeks.

4.3 Alternative policy approaches

We now compare the performance of the alternative policies by examining the long-term hunger rate (Table 4 and Figure A1), initial stocks (upper panel in Table 5 and Figure A2) and frequency of stockouts (lower panel in Table 5). All the results presented here are based on Monte Carlo

Variable	Stat.	Scenario 1: (baseline)		Scenario 2: $\rho = 3.0$		Scenario 3: $\psi = 4$		Scenario 4: $\phi = 0.05$		Scenario 5: $P_H = 1.60$	
		p_L	p_H	p_L	p_H	p_L	p_H	p_L	p_H	p_L	p_H
Tax rate, %	min	1.02	-30.45	1.22	-31.94	0.72	-23.90	0.89	-20.72	0.39	-17.23
	mean	3.34	-11.70	3.79	-12.99	2.02	-7.05	2.01	-6.17	1.39	-5.03
	max	10.83	-0.00	11.91	-0.00	7.35	-0.00	6.70	-0.00	5.07	-0.00
Initial stock	min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	mean	3.86	1.67	4.46	2.01	2.88	0.94	1.73	0.63	1.51	0.55
	max	5.14	5.14	6.14	6.14	3.65	3.65	2.18	2.18	1.95	1.95
End stock	min	1.29	0.00	1.41	0.00	0.89	0.00	0.80	0.00	0.62	0.00
	mean	4.17	0.41	4.81	0.60	3.06	0.21	1.89	0.01	1.64	0.01
	max	5.14	1.70	6.14	2.46	3.65	1.10	2.18	0.04	1.95	0.05
Food price	min	1.00	1.09	1.00	1.08	1.00	1.13	1.00	1.15	1.00	1.10
	mean	1.01	1.19	1.01	1.19	1.01	1.22	1.01	1.22	1.00	1.16
	max	1.04	1.25	1.04	1.25	1.02	1.25	1.02	1.25	1.02	1.18
Hunger rate, %	min	44.64	48.07	44.66	47.75	44.60	49.43	44.62	50.06	44.55	48.50
	mean	44.94	51.64	45.00	51.39	44.77	52.51	44.77	52.67	44.69	50.57
	max	45.92	53.77	46.05	53.77	45.47	53.77	45.39	53.77	45.17	51.42

Stocks are normalized as weeks of normal-period imports in "baseline". Columns p_L (p_H) indicate a tranquil period (food crisis). For each scenario, the heading shows the parameter that differs from baseline.

Table 3: Policy Case A: Results for All Scenarios

Scenario	State	Policy A: base	Policy B: cash?	Policy C: welfare?	Policy D: volatility?	No policy
1: Baseline	tranquil	44.9	44.7	44.7	46.7	44.5
	crisis	51.6	53.1	52.6	47.5	53.8
	(all)	46.3	46.3	46.3	46.8	46.4
2: Higher aversion	tranquil	45.0	44.7	44.7	46.7	44.5
	crisis	51.4	52.7	52.6	47.5	53.8
	(all)	46.3	46.3	46.3	46.8	46.4
3: Longer crisis	tranquil	44.8	44.6	44.6	46.7	44.5
	crisis	52.5	53.4	53.4	47.8	53.8
	(all)	46.3	46.3	46.3	46.9	46.4
4: Higher cost	tranquil	44.8	44.7	44.5	46.7	44.5
	crisis	52.7	53.1	53.6	48.4	53.8
	(all)	46.3	46.3	46.3	47.0	46.4
5: Lower PgH	tranquil	44.7	44.6	44.5	46.1	44.5
	crisis	50.6	51.2	51.2	46.9	51.4
	(all)	45.9	45.9	45.9	46.2	45.9

Each Scenario ~ Policy pair is based on 10^5 Monte Carlo replications.

Table 4: Mean Hunger Rate

simulations. The histograms shown in the figures are conditional on the international price of grain.

In terms of the unconditional hunger rate, we find that using a financial reserve (Policy B) or focusing on welfare (Policy C) do not differ from fighting hunger with a grain buffer stock. In scenarios 1 to 4, these policies achieve the same hunger rate of 46.3%, a very modest reduction from the 46.4% that would prevail in the absence of policy. In scenario 5 (where crisis are milder) the policies would have no effect on the long-term hunger rate.

Where these policies do differ is in how much they isolate the country from grain price shocks. When the objective is hunger reduction, a grain reserve is more effective than a financial reserve in reducing hunger during crises (see Figure A1). For example, in the baseline scenario, the average hunger rate during crises is reduced from 53.8% to 51.6% with a grain reserve, but only to 53.1% with a financial one. This result follows from the different size of the respective reserves (see Figure A2): while during crises the government would have an average of 1.7 weeks of grain in a buffer stock, it would only have deposits worth 0.5 weeks of grain imports. Both policies respond similarly to the milder crisis in Scenario 5, with a reduction of approximately 65% on the average reserve. However, the cash reserve is significantly more sensitive than the grain reserve to risk aversion and to the duration of crisis. While the average grain reserve is 14% higher than in baseline when risk aversion is increased from 2.5 to 3.0 (scenario 2), the average deposit is 52% higher. Similarly, a

Scenario	State	Policy A: base	Policy B: cash?	Policy C: welfare?	Policy D: volatility?
		Average stocks at beginning of period (weeks)			
1: Baseline	tranquil	3.9	2.2	1.8	34.3
	crisis	1.7	0.5	0.6	26.8
	(all)	3.4	1.8	1.5	32.8
2: Higher aversion	tranquil	4.5	3.4	1.9	34.3
	crisis	2.0	0.8	0.7	26.8
	(all)	4.0	2.9	1.6	32.8
3: Longer crisis	tranquil	2.9	1.4	0.7	37.4
	crisis	0.9	0.2	0.2	26.0
	(all)	2.5	1.1	0.6	35.1
4: Higher cost	tranquil	1.7	2.2	0.3	19.3
	crisis	0.6	0.5	0.1	12.9
	(all)	1.5	1.8	0.2	18.0
5: Lower PgH	tranquil	1.5	0.7	0.3	22.9
	crisis	0.6	0.2	0.1	17.1
	(all)	1.3	0.6	0.3	21.8
		Frequency of stockouts (percent)			
1: Baseline	tranquil	0.1	0.1	0.1	0.0
	crisis	0.5	0.5	0.7	0.1
	(all)	0.1	0.1	0.2	0.0
2: Higher aversion	tranquil	0.0	0.1	0.1	0.0
	crisis	0.4	0.4	0.7	0.1
	(all)	0.1	0.1	0.2	0.0
3: Longer crisis	tranquil	0.0	0.1	0.1	0.0
	crisis	0.6	0.6	0.7	0.1
	(all)	0.1	0.2	0.2	0.0
4: Higher cost	tranquil	0.1	0.1	0.1	0.0
	crisis	0.5	0.5	0.7	0.2
	(all)	0.2	0.1	0.2	0.1
5: Lower PgH	tranquil	0.1	0.1	0.1	0.0
	crisis	0.6	0.7	0.7	0.1
	(all)	0.2	0.2	0.2	0.0

Each Scenario ~ Policy pair is based on 10^5 Monte Carlo replications.

Table 5: Average Stocks and Frequency of Stockouts

one-quarter longer crisis (scenario 3) induces a reduction on stocks of 28% on grain holdings but 41% on deposits. Moreover, as expected, the cash reserve is not affected by a change in the cost of storing grain (scenario 4).

Furthermore, if the government's objective in holding a grain reserve is to maximize social welfare rather than to prevent extreme hunger, the resulting optimal reserve is considerably smaller (see figure A2). For example, in Scenario 1 the long-term average of the grain stock is 54% smaller when the objective is welfare. In consequence, during crises the average hunger rate reduction achieved by following policy C is only around half of the reduction achieved under policy A.

Thus, we find that the country would be better insulated from a jump in grain prices if it stores grain to fight hunger. But it is important to notice that the three policies considered so far have the same unconditional hunger rate, and therefore the implementation of the baseline policy is only possible by inducing a higher increase in the hunger rate of tranquil periods.

Moreover, none of these policies would significantly reduce the frequency of the highest hunger rate, because the optimal stocks (either cash or grain) are small and crises are frequently faced with an empty reserve (see lower panel of Table 5). For example, when storing grain to fight hunger, stockouts occur in 46% of crisis periods.

Suppose now that the government is determined to stabilize the hunger rate by fixing the price of grain at its stationary mean (policy D). From the last row of histograms in Figure A1 it is clear that this policy would greatly reduce the number of extreme hunger episodes, although it would not completely avoid them because there would still be occasional stockouts⁸. But to achieve this level of stabilization, the government would need to carry much larger reserves. For example, in the baseline scenario the average reserve would be 33 weeks, and the required storage capacity would be 1.5 years of grain, 28 times bigger than the planned storage complex in Haiti. Given the cost of storing such large stocks, this policy would actually increase the unconditional hunger rate by one half of a percentage point.

4.4 Efficacy of the reserve policy

In this section, we discuss some insights about the efficacy of the storage policy in improving food security. We take the baseline model as reference.

First, the reserve cannot avoid extreme hunger. In many instances, a crisis will hit the country

⁸This confirms Townsend (1977)'s result that all price-fixing schemes eventually fail.

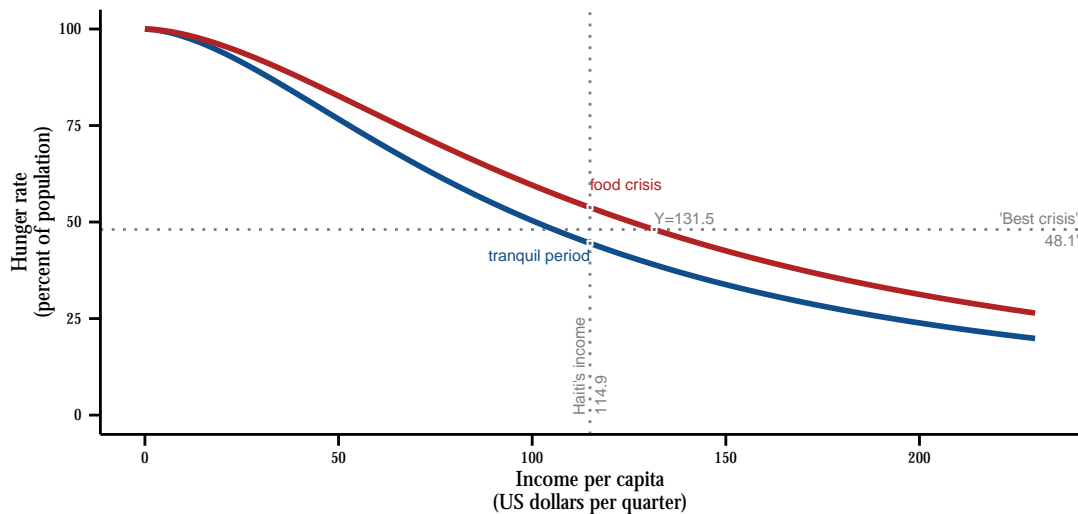


Figure 8: Income Per Capita and Hunger

An increase in income per capita reduces hunger. The best crisis hunger rate of 48.1% achieved by the storage policy can also be obtained (without policy) if income per capita increases by 14.4%.

when the reserve is empty. The reserve can at best reduce the frequency of extreme hunger.

Second, a grain reserve has the potential to reduce the hunger rate during a crisis (from 53.8% to 48.1% in the best case, when the initial reserve is full). Yet this reduction is rather modest. For instance, Figure 8 shows the hunger rate as a function of income per capita, for each price state. It follows that the highest protection offered by the reserve can be achieved if income per capita increases 14.4%. Over the course of two average grain price cycles (7.5 years), this would require an annual growth rate of 1.8%. Moreover, due to stockouts the hunger rate is reduced on average only to 51.6%; this level of protection can be achieved by a 5.2% increase in income per capita.

Alternatively, Figure 9 shows that the best protection can be achieved by a redistribution of income, reducing the Gini coefficient from 0.59 to 0.54 (or to 0.57 for the average case). This final result deserves consideration: It should be remembered that in this study the policy intervention is neutral with respect to the income distribution because the import tariff-subsidy rate is the same for all households. The storage policy in our model is ineffective at preventing jumps in the hunger rate, one could argue, because it does not limit the subsidy to only the poorest households. But doing so results in a *redistributive* policy, that is, in a reallocation of resources across households, while a reserve is a tool for *intertemporal* allocation. Following this logic, if the policy objective is to

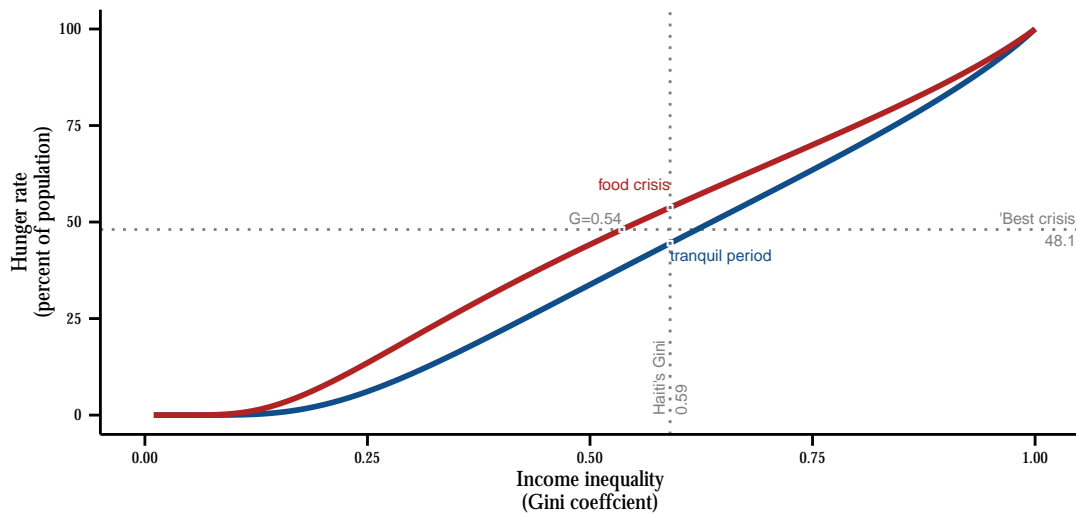


Figure 9: Income Inequality and Hunger

A decline in income inequality reduces hunger. The best crisis hunger rate of 48.1% achieved by the policy can also be obtained (without policy) if the Gini coefficient dropped from 0.59 to 0.54.

offer protection to vulnerable households, why not do it also during tranquil periods? Consequently, a safety net might be a better response to food price shocks (Yemtsov and Gentilini 2014).

5 Conclusions

Here we develop a model to evaluate the cost and benefit of establishing a grain reserve in a poor, grain-importing country. Given that the main concern regarding the impact of the Global Food Price Crisis is the increased number of people suffering hunger when food becomes expensive, in the model the explicit objective of the reserve is to prevent extreme hunger. Furthermore, to be sustainable, the policy must raise enough revenue (through tariff) in tranquil periods to afford helping households during crises. We use the model to assess the potential impact of maintaining a food reserve in Haiti.

Our main results are as follows: Without a government buffer stock, a crisis induces a 25% increase in the food price and raises the hunger rate from 44.5% to 53.8% of the population. To address the possibility of such crises, the optimal policy calls for maintaining a grain reserve equal to 5.1 weeks of average consumption. This amount of grain would allow the government to reduce hunger from 53.8% to 48.1% at the peak of the crisis. However, once the reserve is depleted, the

government would be unable to further alleviate a crisis that lasts for more than two periods. Once depleted, replenishing the reserve requires an 11% tariff, which would raise the hunger rate from 44.5% to 45.9% during tranquil periods. We find that more often than not the storage policy would fail to reduce hunger during crises, because the reserve would have been depleted. This finding is robust to whether the government accumulates cash instead of grain.

As mentioned in the introduction, Gouel (2013) finds that because public buffer stocks crowd out private storage, the welfare gains of implementing this policy are low. Our results show that the benefits of buffer stocks can be low even in poor countries where there is no private storage.

More importantly, our results suggest that rather than storing food, a better approach for a poor country would be to fight poverty directly, since the modest social protection provided by a storage policy could be also be obtained through relatively small improvements in income per capita and income distribution. For example, during crises the storage policy reduces the average hunger rate from 53.8% to 51.6%. Without the storage policy, this result can be achieved by either a 5% increase in income per-capita or by reducing income inequality from 0.59 to 0.57 (Gini coefficient).

References

Appendix: Additional Figures

Figures A1 to A3 present results for all five scenarios and three policy stances.

Appendix: Estimating the demand for hunger

In the theoretical model, we solved for the optimal storage policy when the ultimate objective was the reduction of hunger. To make the model operational, we derived a hunger rate for the country, based on the two critical assumptions: first, that income follows a log-logistic distribution; and second, that the price- and income- elasticities of the food demand are constant. Combining the two assumptions, it follows that food consumption has a log-logistic (a_f, b_f) distribution. Hunger is then defined in equation (8) with respect to a critical consumption level c . In this appendix, we show that this framework fits data from countries in the Economic Community Of West African States (ECOWAS) and the Association of Southeast Asian Nations (ASEAN) remarkably well.

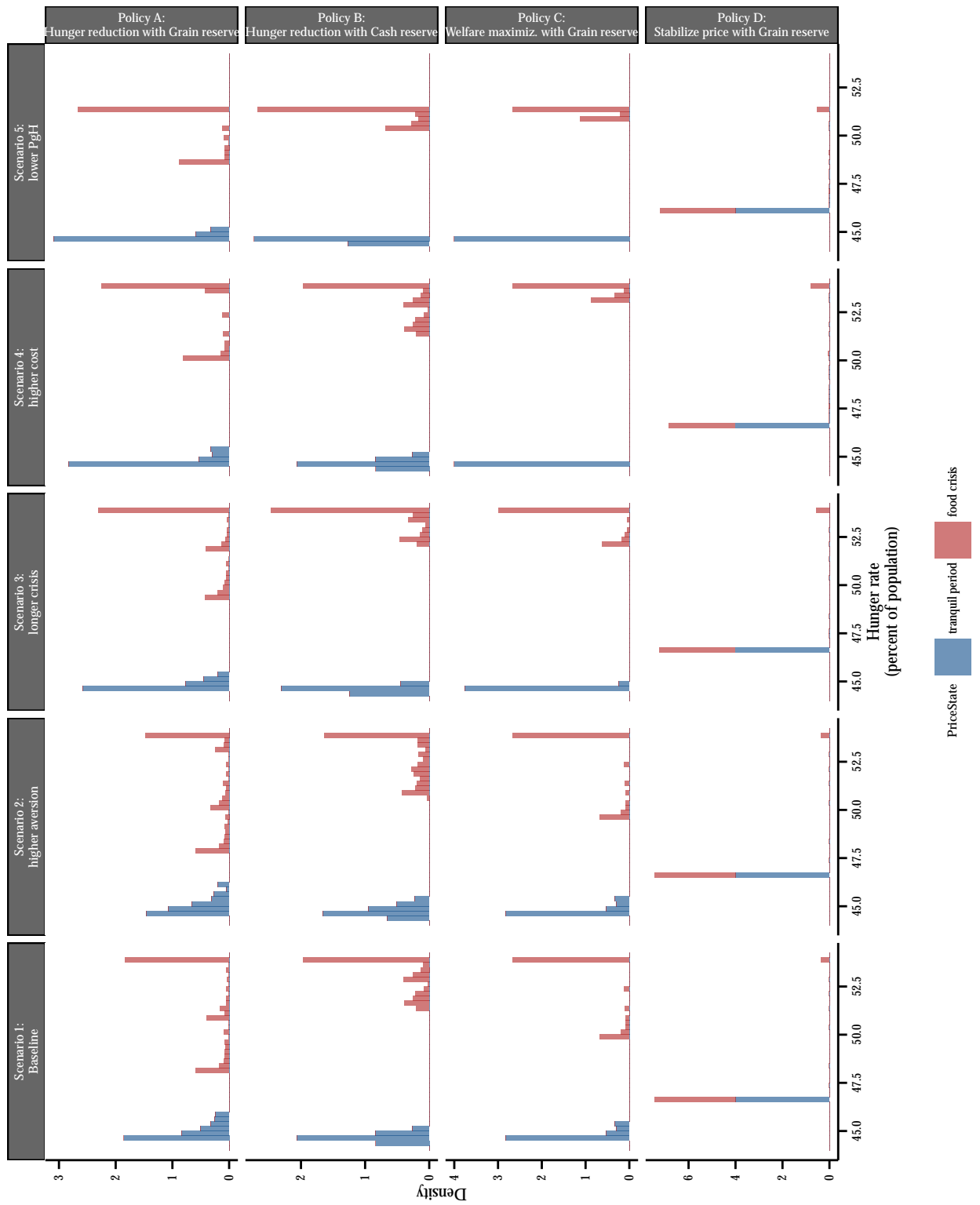


Figure A1: Hunger Histogram

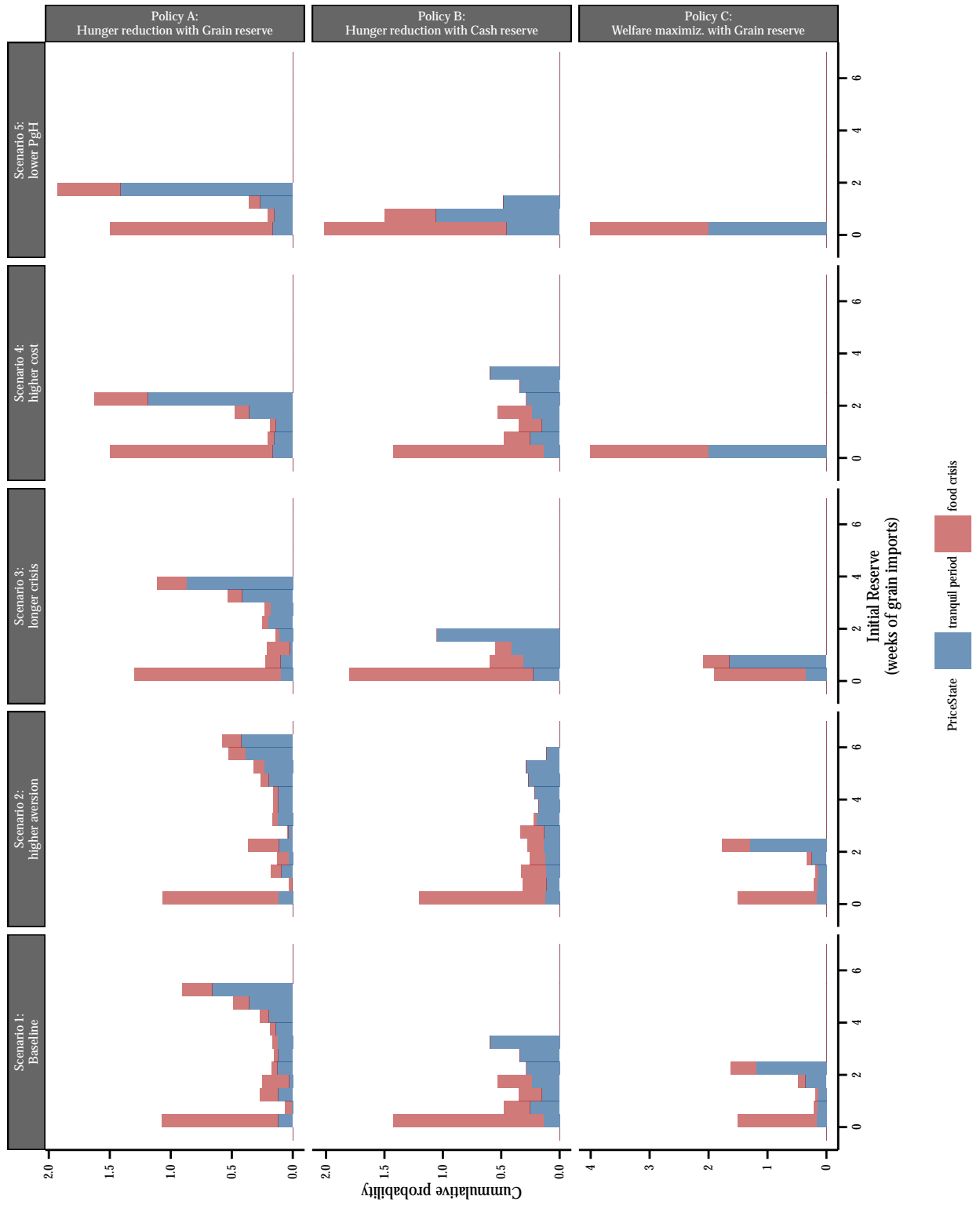


Figure A2: Grain Storage Histogram

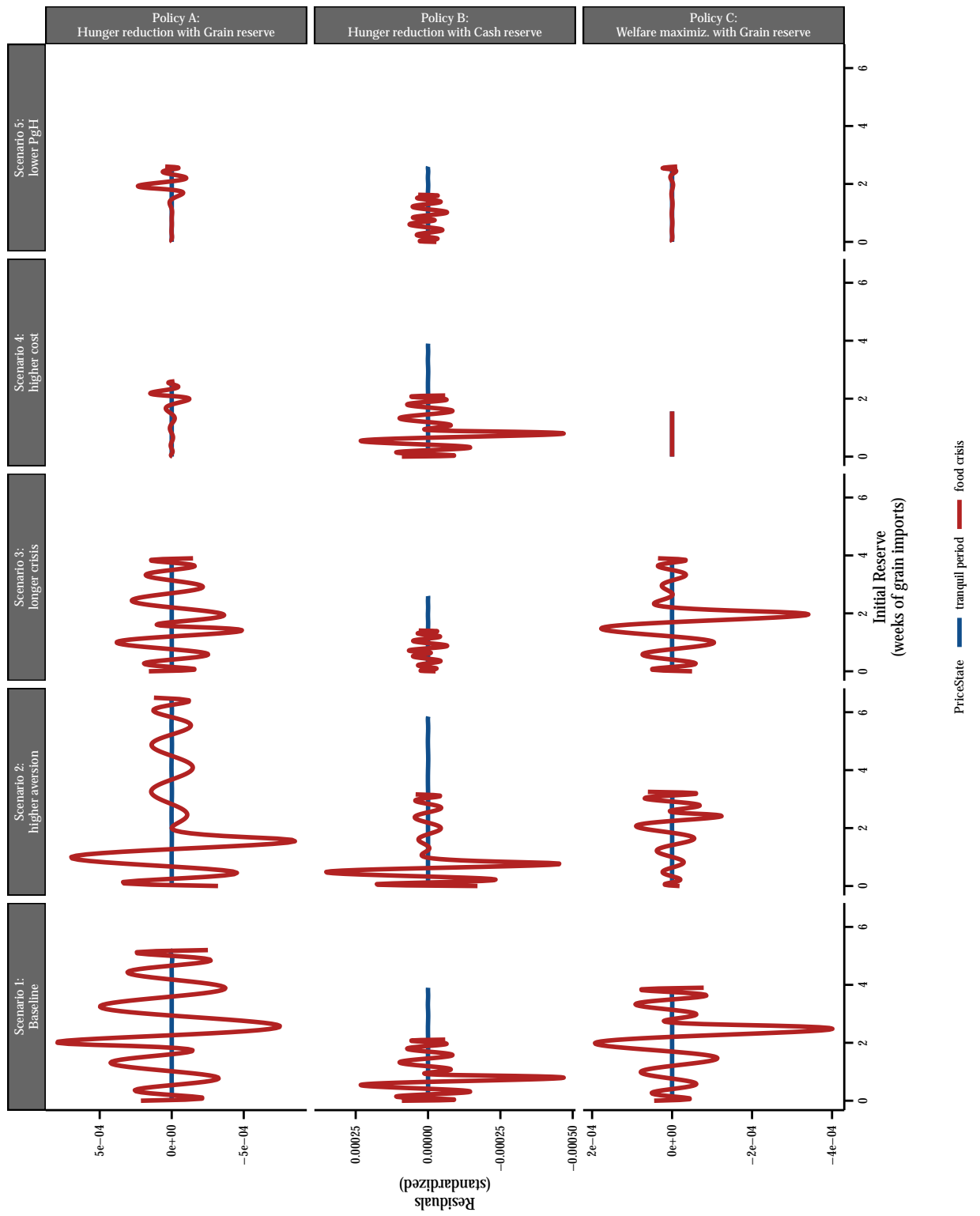


Figure A3: Residuals

The first step in testing the model is to obtain an “empirical” equation. In equation 8 we obtained the hunger rate $\Gamma = \left[1 + \left(\frac{c}{a_f}\right)^{-b_f}\right]^{-1}$; it follows that

$$\frac{\Gamma}{1-\Gamma} = \left(\frac{c}{a_f}\right)^{b_f} \quad (13)$$

Next, substitute a_f using the expected value of consumption $\mathbb{E}c = a_f \frac{\pi}{b_f} \csc\left(\frac{\pi}{b_f}\right)$ and take logarithms in (13) to obtain:

$$\log\left(\frac{\Gamma}{1-\Gamma}\right) = b_f \left[\log c + \log\left(\frac{\pi}{b_f}\right) - \log \sin\left(\frac{\pi}{b_f}\right)\right] - b_f \log \mathbb{E}c$$

Let $\zeta = b_f \left[\log c + \log\left(\frac{\pi}{b_f}\right) - \log \sin\left(\frac{\pi}{b_f}\right)\right]$. Assuming that the observed average consumption c_{it} for country i at year t is related to its expected value by $c_{it} = \exp\left(\frac{\epsilon_{it}}{b_f}\right) \mathbb{E}c$, where $\mathbb{E}\epsilon_{it} = 0$:

$$\log\left(\frac{\Gamma_{it}}{1-\Gamma_{it}}\right) = d^* - b_f \log c_{it} + \epsilon_{it} \quad (14)$$

In a final step, we assumed that observed average consumption is a fraction ϖ of the average amount of food available in the country (x_{it}): $c_{it} = \varpi_i x_{it}$. This fraction is constant over time, but differs from country to country. Equation (14) becomes:

$$\log\left(\frac{\Gamma_{it}}{1-\Gamma_{it}}\right) = d_i^* - b_f \log x_{it} + \epsilon_{it} \quad (15)$$

where $d_i^* = d^* - b_f \log \varpi_i$.

We estimated (15) for a sample of 18 countries (twelve from ECOWAS and six from ASEAN), with annual observations in 1991 to 2011 (378 total observations). Data was obtained from FAO - Food Security Indicators⁹. The hunger variable Γ is measured by the prevalence of undernourishment (V12), which corresponds to the proportion of the population estimated to be at risk of caloric inadequacy¹⁰. On the other hand, the average food available x is measured by the average dietary energy supply adequacy (V01), which corresponds to the ratio of the dietary energy supply to the average dietary energy requirement in the country¹¹.

The result of estimating (15) as a fixed effects model is illustrated in figure A4.

⁹Available at <http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/>.

¹⁰This is the FAO hunger indicator used to evaluate progress for goal 1, target 1.9 of the Millennium Development Goals.

¹¹Following this definition, we can set $c = 1$.

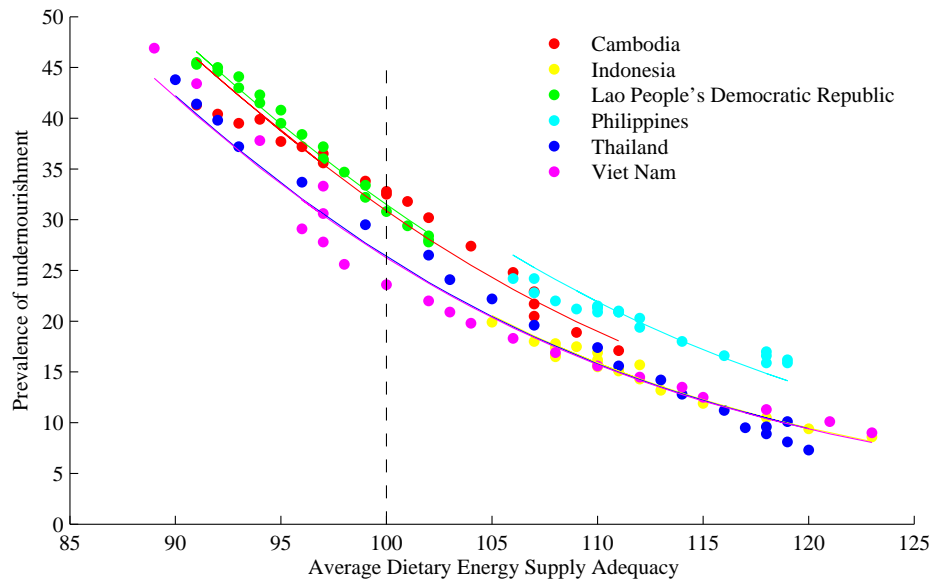
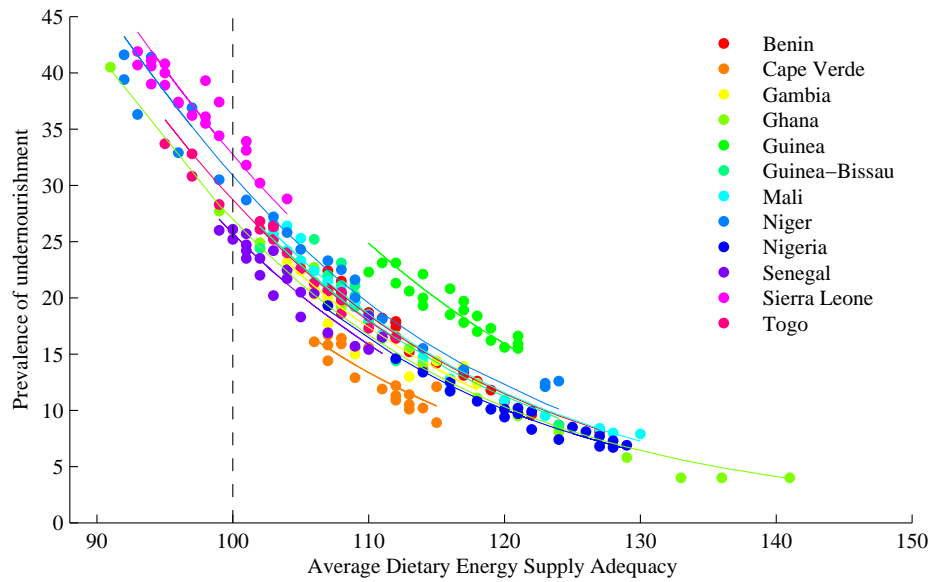


Figure A4: Food adequacy and hunger in ECOWAS and ASEAN countries
 In ECOWAS12 (top panel) and ASEAN (bottom panel) countries, additions to the *average* food supply induce a decline in the prevalence of undernourishment. More than one-quarter of the population goes hungry in a country with *just enough* food (100). Note that even in countries with more than enough food (say 120), the undernourishment rate is between 10 and 20 percent.

List of symbols

PARAMETERS

Γ hunger rate

Other symbols

α price elasticity of food demand

η income elasticity of food demand

ϕ cost of grain storage

π_{ij} transition probability between food price states

ρ government's aversion to hunger

σ elasticity of substitution between ingredients

θ share of grain in recipe

ζ food demand scale

a_f food consumption distribution scale (excluding price effect)

a_y income distribution scale

b_f food consumption distribution shape

b_y income distribution shape

c critical food consumption

G income Gini coefficient

p_H international price of grain, food crisis

p_L international price of grain, tranquil period

Y income per capita

Other symbols

τ import tariff rate

Υ fiscal revenue

D government's deposits

f quantity of food

M_i household i 's food budget

P food price index

p_g domestic price of grain

p_g^* international price of grain

p_v domestic price of vegetable

s grain stock at beginning of period

x_g quantity of grain

x_v quantity of vegetables

y_i household i 's income

Other symbols

\mathbb{S} summation over income distribution

F_y income distribution (cdf)

F_{food} food consumption distribution (cdf)

r_H government reward function, hunger target

r_W government reward function, welfare target

V government's value function

W social welfare