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Storage Policies: Stockpiling Versus Immediate Release

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Abstract:
Storage policies are used in many countries to smooth price volatility and thereby support food security. When there is a global decrease in food supply caused by a number of extreme weather effects, food reserves are expected to reduce the potential negative implications for households with low purchasing power. In this paper, the properties of such a stockpiling policy are assessed and compared to a policy with storage but without stockpiling. The results show that a stockholding policy is an expensive strategy that generates economic benefits only in extreme cases.

Keywords: food crisis, grain reserves, hoarding, stockpiling, storage, uncertainty

JEL classification: O, Q

DOI: 10.1515/jafio-2019-0055

1 Introduction

Storing agricultural products to smooth the supply of food has a long history in agriculture. Processing milk into different kinds of cheeses or meat into sausages, ham, or dried meat are some of the methods applied for animal products. Fruits and vegetables are dried or fermented to preserve them. Similarly, grains are processed into bread, beer, et cetera, to store nutrients for a longer period of time (Toussant-Samant 2009).

Early on, governments were involved in the storage of grains. The biblical story of Joseph's agricultural policy on grain storage is a well-known example about storing grain during good years for use during bad years when harvests are less bountiful. Technologies and markets have been further developed, whereby grain yield has increased substantially and storage facilities have been improved. International trade allows open economies to smooth supplies over the year via the import and export of food products. In addition, countries import food products in exchange for non-food products. Both the public (government) and private sectors are involved in food storage policies (see e. g. Schmitz 2018), with government involvement in particular increasing in importance (Lassa et al. 2019).

Not all government trade policies are characterized by openness to trade. Import and export policies and other domestic trade policies limit the free exchange of goods and services. The development of infrastructure to exchange goods and services is often hampered by government policies. Similarly, access to innovations that improve agricultural production and the control of markets for importing and trading agricultural inputs are also hampered by government policies, resulting in substantial welfare losses (Wesseler and Zilberman 2014; Wesseler et al. 2017). Governments limit market forces to smooth supply and demand of food products, and such limits substitute food storage policies. The objectives of smoothing food supply, reducing fluctuations in consumer prices, and increasing food self-sufficiency are all components of food security policies.

As an extensive review of the literature by Wright (2009) shows, most publicly managed food reserves have a number of shortcomings (some are mentioned above). Nevertheless, in cases where extreme events result in food shortage shocks, food emergency reserves can help to reduce negative impacts for households with low purchasing power. These cases are rare but may increase in the future due to climate change.

In this paper, a simple model will be presented assessing the economic benefits and costs of a public food storage policy. That is, a policy whereby government agencies invest in food storage facilities, and then buy, store, and release food.

The economic benefits and costs of a public food storage policy are assessed by comparing a stockpiling policy strategy (Policy A) with a restocking policy strategy (Policy B) for food distribution during a food crisis. With Policy A, the stockpile inventory is distributed when a food crisis occurs. With Policy B, the just-in-time (immediate release) inventory is restocked when a food crisis occurs. Due to the uncertainty of the length of the food crisis, results show that Policy B (restocking food policy) is the better strategy because Policy A (stockpiling food policy) is more costly.

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The previous literature addressing storage policies shows that the welfare effects of supply and demand uncertainty can be softened by storage policies (van Kooten and Schmitz 1985; van Kooten, Schmitz, and Furtan 1988). This paper differs from the earlier literature by allowing for international trade (imports) and explicitly considering government costs for maintaining a buffer stock.

2 The Economic Model of Stockpiling Food

The objective is to assess public investment in storage facilities at the country level by using a model of investment in storage under time uncertainty. The model includes two specifications (Policy A and Policy B). In the first specification (Policy A), food is stored by the government until a food crisis emerges and then stocks are released to soften the food crisis. In the second specification (Policy B), food is not stored but immediately released when the food crisis emerges, in which food is imported or exports are restricted by the government. The results of the two model specifications will be compared.

At $t_0 = 0$, the storage facilities are available and filled with grain. The investment cost for establishing the facilities is I. At time t_1, which is uncertain, food shortage occurs and food prices increase. A decision maker needs to decide whether or not to release grain from the storage facilities immediately at t_0 or withhold the release until t_1. The net-present-values (NPVs) are modeled for both decisions. The benefits and costs accrue over time and are discounted at the annual rate $\mu > 0$. The differences in the NPVs represent the value of the option of stockpiling food.

Because the storage facilities are available at time t_0, the investment costs do not affect the option value of stockpiling food. Uncertainty is introduced with respect to the time length of the periods with and without a food crisis.[1]

2.1 Policy A: Stockpile Food until Food Crisis Occurs

The distribution of food is held off until a significant increase in food prices has occurred at an uncertain time, t_1. The model for Policy A calculates the NPV of stockpiling food until t_1 and releasing food over the period $t_2 - t_1$.

The cost of stockpiling food before the food crisis is denoted by C_S. The start of the food crisis is uncertain and occurs at $t_1 = \kappa_1$. The uncertain start of the food crisis is modeled by letting κ_1 follow the exponential distribution $g(k_1) = h_1 e^{-h_1 k_1}$, with $E(k_1) = 1/h_1$, where $h_1 > 0$ denotes the so-called hazard or failure rate, and $E(k_1)$ denotes the mean time between failures (Pinsky and Karlin 2011) or the mean time between food crises. The length of the food crisis, κ_2, is exponentially distributed with $g(k_2) = h_2 e^{-h_2 k_2}$, with $E(k_2) = 1/h_2$, where $h_2 > 0$ again denotes the hazard or failure rate of $E(k_2)$.

The costs of distributing and stockpiling part of the food during the crisis are C_D with $C_D \geq C_S$, as during the distribution of food, storage costs still apply because not all food is distributed at once. The availability of food during the food crisis provides additional benefits of B_{D1}. They include the avoided economic costs that would have been incurred in the absence of stockpiling food and can be seen as the sum of consumer and producer surplus, similar to van Kooten and Schmitz (1985).

During food distribution, the benefits of distributing food decrease as more food is released. The decrease is modeled by introducing a decay rate $\delta > 0$. The effective annual benefits of releasing food during the food crisis are $B_{D1} e^{-\delta(t-k_1)}$, for $k_1 \leq t < k_1 + k_2$. After the food crisis has ended, the storage facilities will be restocked and food will be stockpiled until the next food crisis. This is not explicitly considered in the model. Policy A is summarized in Figure 1.

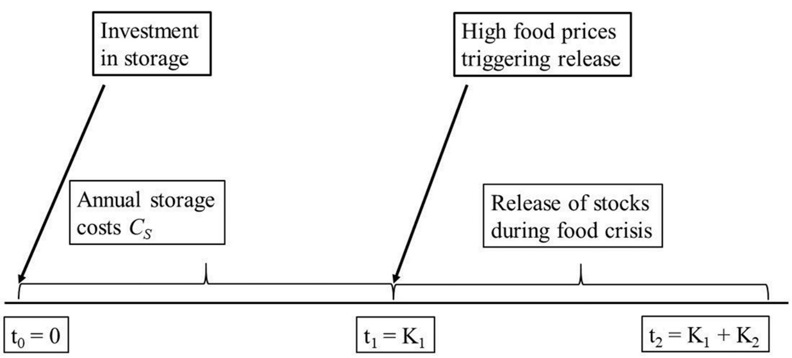

Figure 1: Stockpiling food until food crisis.

The NPV of Policy A provides the following result by applying the functional forms for the uncertain times κ_1 and κ_2. The costs of stockpiling:

$$C_H = \int_0^\infty \left[\int_0^{k_1} C_S e^{-\mu t} dt \right] g(k_1)\, dk_1 = \frac{C_S}{\mu + h_1} \tag{1}$$

Benefits minus costs during food crisis:

$$B_{CA} = \int_0^\infty \left\{ \int_0^\infty \left[\int_{k_1}^{k_1+k_2} \left(B_{D1} e^{-\delta(t-k_1)} - C_{D1} \right) e^{-\mu t} dt \right] g(k_1)\, dk_1 \right\} g(k_2)\, dk_2 = \frac{h_1}{\mu + h_1} \left(\frac{B_{D1}}{r + \mu + h_2} - \frac{C_{D1}}{\mu + h_2} \right) \tag{2}$$

Collecting terms provides the following NPV for the stockpiling policy (Policy A):

$$NPV_A = -I - C_H + B_{CA} \tag{3}$$

2.2 Policy B: Immediate Release of Food without Stockpiling

Under the Policy B strategy, investments in food storage are made, but food is immediately and continuously released (just-in-time inventory); once storage facilities are emptied, food will be restocked (see Figure 2). Restocking will depend on the quantity of food being released from the storage facility; is expected to take time, $t_f - t_1$; and is done by importing food from abroad. The time needed for restocking is exponentially distributed, with $g(k_F) = h_F e^{-h_F k_F}$, recognizing that the time length for restocking storage facilities is uncertain. Restocking requires additional stocking costs s_R and is done via imports.

The NPV of Policy B provides the following result by applying the functional forms for the uncertain times κ_1, κ_f, and κ_2. The benefits and costs of immediate distribution before the food crisis:

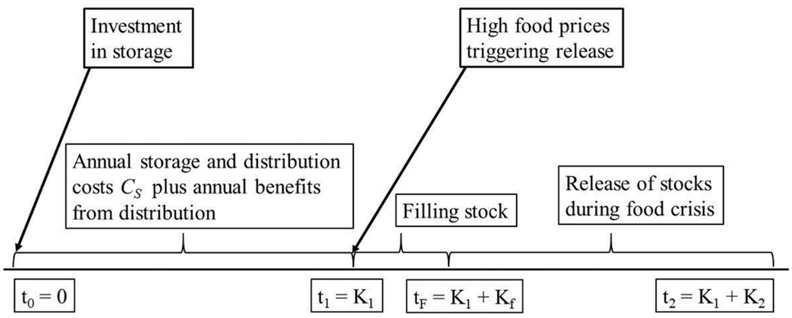

Figure 2: Storing and immediately distributing food.

$$B_{BC} = \int_0^\infty \left[\int_0^{k_1} \left(B_{D0} - C_{D0} \right) e^{-\mu t} dt \right] g(k_1)\, dk_1 = \frac{B_{D0} - C_{D0}}{\mu + h_1} \tag{4}$$

Restocking costs with start of the food crisis:

$$S_R = \int_0^\infty \left\{ \int_0^\infty \left[\int_{k_1}^{k_1+k_f} s_R e^{-\mu t} dt \right] g(k_1)\, dk_1 \right\} g\left(k_f\right) dk_f = \frac{h_1 s_R}{(\mu + h_1)\left(\mu + h_f\right)} \tag{5}$$

Benefits minus costs during the crisis, with $(\delta\text{-}h_f) < 0$:[2]

$$B_{CB} = \int_0^\infty \left\{ \int_0^\infty \left\{ \int_0^\infty \left[\int_{k_1+k_f}^{k_1+k_2} \left(B_{D1} e^{-\delta(t-k_1-k_f)} - C_{D1} \right) e^{-\mu t} dt \right] g(k_1)\, dk_1 \right\} g(k_f)\, dk_f \right\} g(k_2)\, dk_2 = \frac{h_1}{\mu+h_1} \left(\frac{B_{D1} f}{(\mu+f)(\mu+\delta)} + \frac{B_{D1} h_f h_2}{(r-h_f)(\mu+\delta)(\mu+\delta+h_2)} + \frac{C_{D1}(h_2-h_f)}{(\mu+h_f)(\mu+h_2)} \right) \quad (6)$$

The notations used for developing the model are listed in Table 1.

Table 1: Model parameters and variables and their notations.

Parameters/Variables	**Notation**	**Value***
Investment in storage facilities	I	10
Benefits of distributing food before food crisis (Policy B only)	B_{D0}	
Benefits of distributing food during food crisis (Policy A and B)	B_{D1}	
Costs in present value of stockpiling food before crisis	C_H	
Monthly costs of storing food before crisis	C_S	1
Costs storing and distributing food during crisis	C_{D1}	1
Net-benefits in present value during food crisis under Policy A	B_{CA}	
Net-present-value of Policy A	NPV_A	
Costs of storing and distributing food before crisis	C_{D0}	1
Net-benefits in present value of distributing food before crisis (Policy B)	B_{BC}	
Restocking costs during crisis	s_R	1
Total restocking costs in present value	S_R	
Net-benefits in present value during food crisis under Policy B	B_{CB}	
Net-present-value of Policy B	NPV_B	
Expected length before food crisis starts	κ_1	12
Expected length food crisis lasts	κ_2	6
Expected length restocking under Policy B	κ_f	2
Hazard rate for κ_1	h_1	0.0833
Hazard rate for κ_2	h_2	0.1660
Hazard rate for κ_f	h_f	0.5000
Discount rate per month	μ	0.0033
Depreciation of benefits during food crisis per month	δ	0.1943
Time	t	

*Note: Values listed refer to calibration of the model if not explicitly mentioned otherwise.

Collecting terms provide the following NPV for the immediate release policy (Policy B):

$$NPV_B = -I + B_{BC} - S_R + B_{CB} \quad (7)$$

Policy A will be preferable to Policy B if $NPV_A > NPV_B$:

$$\frac{B_{D1}}{\delta+\mu+h_2} - \frac{C_{D1}}{\mu+h_2} - \frac{C_S}{h_1} > \frac{B_{D0}-C_{D0}}{h_1} - \frac{s_R}{(\mu+h_f)} + \frac{B_{D1} h_f}{(\mu+h_f)(\mu+r)} + \frac{B_{D1} h_f h_2}{(\delta-h_f)(\mu+\delta)(\mu+\delta+h_2)} + \frac{C_{D1}(h_2-h_f)}{(\mu+h_f)(\mu+h_2)} \quad (8)$$

The comparison of the two policies presented in eq. (8) is complex. The next section addresses some interesting policy questions using reasonable parameter values. The notations used are listed in Table 1.[3]

3 Further Calibration and Results

One of the interesting questions is how large the food crisis needs to be to justify a pure storage policy (Policy A) from an economic point of view. There are some important boundary conditions that need to be met. First, NPV_A and NPV_B as well as B_{BC} have to be larger than zero (see eq. (3), eq. (7), and eq. (4), respectively). This might be overlooked when only considering eq. (8).

Table 1 illustrates the parameter values chosen for analyzing the results if not mentioned otherwise. The time length chosen is one month. This implies a value of $\varkappa_1$ of 12 is equivalent to one year and a "hazard" rate of $h_1 = 0.0833$. This is similar to the situation where the next harvest in 12 months is low and triggers a food crisis.

The expected time length of the food crisis is six months, $\varkappa_2 = 6$. After six months, the prices are back to normal. The corresponding value for h_2 is 0.166. Under Policy B, stocks need to be refilled. Restocking is expected to take two months, $\varkappa_f = 2$. The corresponding value for h_f is 0.5.

The storage and distribution costs have been normalized to one. An annual discount rate μ of 4 % has been used, which is equivalent to a monthly discount rate of 0.33 %. A monthly depreciation of benefits r of 19.43 % has been used if not mentioned differently. The value of r has been derived for B_{D1} reaching the value of one after 12 months and equivalent with the initial costs of distributing food based on the other values listed in Table 1.

A breakeven value for B_{D1} under Policy A (eq. (3) is set to zero) of 10.29 has been derived based on these parameter values. The breakeven value for B_{D0} under Policy B has been derived using the same parameter values and the results for B_{D1} under Policy A. The breakeven value for B_{D0} is 1.28. The ratio of the two breakeven points equals $10.29/1.28 = 8.06$. The benefits of distributing food during the food crisis justifying a hoarding policy need to be eight times higher than the benefits of distributing food prior to the crisis and restocking when the crisis starts.

This indicates that the food crisis needs to be extremely severe to justify a stockpiling policy based on these parameter values. The values are much higher than the levels reached during the 2007–2010 food crisis, when the FAO food price index increased from around 120 to 200 in nominal values (Food and Agricultural Organization of the United Nations (FAO) 2019).

The FAO food price index reflects average numbers. The situation in an individual country might look differently. In some countries, food prices in nominal terms may increase more strongly to justify a stockpiling policy as indicated by the calibration of the model. If, for example, the depreciation of benefits increases from 0.19 to 0.48 and the food crisis is prevented more rapidly, *ceteris paribus*, the initial benefits for justifying the stockpiling policy, B_{D1}, need to be higher and equivalent to a value of 18.59. In this case, the benefits from distributing food immediately, B_{D0}, need to be even higher and reach a value of 31.45 or more to justify Policy B. The benefits before the crisis need to be higher than the benefits after the crisis. This is an unrealistic situation. Hence, in an extreme case, where benefits B_{D1} are extremely large and the food crisis is quickly solved, a stockpiling policy can be economical.

The situation changes if the length of the food crisis increases to twelve months. Keeping the value for B_{D1} at 18.59, B_{D0} needs only to be 1.55 or higher, resulting in a B_{D0}/B_{D1} breakeven ratio of about 12.03.

As mentioned before, these are average numbers and food prices in nominal terms in some countries might increase more strongly. For example, an increase in the price of tortillas by a factor four was reported for Mexico in 2007 (Thomaz and Carvalho 2011). Although this is a substantial increase in the price of a staple food, it is not as high as would be needed to justify a stockpiling policy.

If the benefit depreciation is increased and the food crisis is prevented more rapidly, *ceteris paribus*, the initial benefits for justifying the stockpiling policy, B_{D1}, need to be even much higher and equivalent to a value of 18.59. In this case, the benefits from distributing food immediately, B_{D0}, need to reach a value of 31.45 or more to be economical. Benefits before the crisis need to be higher than benefits after the crisis, thus an unrealistic scenario.

The situation changes if the length of the food crisis increases to twelve months, keeping the value for B_{D1} at 18.59. In this case, B_{D0} needs only to be 1.55 or higher for Policy B to be economical. This is equivalent to a B_{D0}/B_{D1} breakeven ratio of about 12.03.

3.1 The Length of a Crisis

The results of the model largely depend on the benefits during a crisis and the speed of crisis prevention. The benefits of a stockpiling policy depend largely on how quickly a crisis can be eliminated. The larger the depreciation r of the benefits, B_{D1}, the more quickly a response to a crisis will be. In the current model setting, this will result in lower benefits compared to a situation where the crisis will last longer, *ceteris paribus*. In other words, a quick, immediate response generates lower benefits than a slower, longer-term response for any given initial benefits and costs. This is a relevant tradeoff, and needs to be considered when comparing the results of higher and lower depreciation in benefits, and requires modifications of the model. In the context of this study, however, it is less relevant because a comparison is made between stockpiling and immediate release/restocking.

Figure 3 illustrates the results for different expected lengths of a food crisis, $\varkappa_2$, on the breakeven value for B_{D0}. The results are derived as follows. First, the breakeven value for B_{D1} is calculated for a given value of $\varkappa_2$ and an equivalent depreciation value of r. Second, using the values listed in Table 2 to calculate the breakeven value for B_{D0}, $\varkappa_2$ is changed by keeping the value for B_{D1} fixed conditional on an initial value for $\varkappa_2$. Third, the equivalent depreciation values of r and the breakeven values for B_{D0} are calculated.

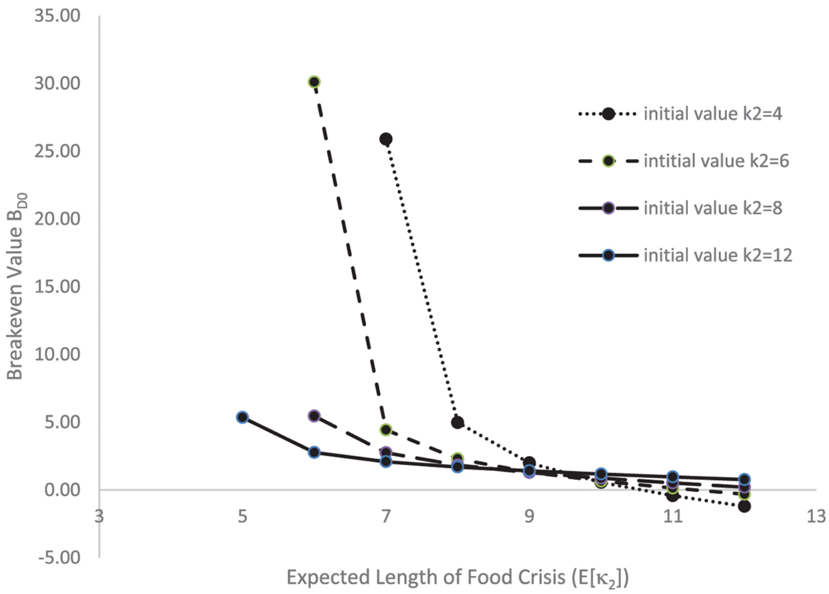

Figure 3: Effect of change in expected length of food crisis (E[$\varkappa_2$]) on breakeven value of B_{D0}.

Table 2: Values for model calibration (time measured in months).

Variables	Value	Time Length, $\varkappa$
Investment in storage I	10	
Storage costs before crisis C_s (Policy A)	1	
Distribution costs before crisis C_{D0}	1	
Distribution costs during crisis C_{D1}	1	
Restocking costs during crisis s_R	1	
Hazard rate until crisis $\varkappa_1$, h_1	0.0833	12.00
Hazard rate for length of crisis $\varkappa_2$, h_2	0.1660	6.00
Hazard rate for length of restocking $\varkappa_f$, h_f	0.5000	2.00
Discount rate per month μ	0.0033	
Benefit depreciation per month, r	0.1943	

As illustrated in Figure 3, the breakeven values decline with an increase in the expected length of a food crisis. The decline in the breakeven values is more strongly pronounced for lower initial values of $\varkappa_2$. Appendix Table 3 lists the corresponding values as well as the ratio B_{D1}/B_{D0}. This ratio increases exponentially. The longer the expected length of a food crisis, the less economical the stockpiling policy will be.

3.2 Effect of a Change in the Length of Restocking, $\varkappa_f$, on Ratio B_{D1}/B_{D0}

The Policy B scenario has additional costs compared to the Policy A scenario in the form of the restocking cost S_R Figure 4 illustrates the effect of a change in the length of restocking, $\varkappa_f$, on the ratio B_{D0}/B_{D1}. The ratio decreases quickly with an increase in the length of the time needed for restocking food reserves. This is a strong indication that from an economic point of view, the infrastructure needed for quickly restocking food is important if Policy B is implemented. The ratio is still larger than one for a length in restocking of about 4.26 months.

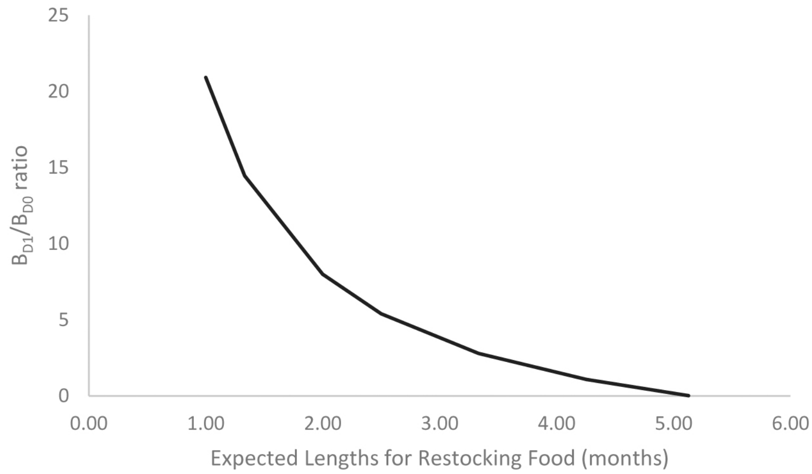

Figure 4: Effect of restocking length on B_{D0}/B_{D1} ratio.

3.3 Effect of Differences in Time Length $\varkappa_1$

The expected length of a food crisis to occur, $\varkappa_1$, also has an impact on the breakeven ratio. The sooner the food crisis is expected to occur, the higher the benefits of a stockpiling policy will be. The simple economic reasoning is that the benefit of immediate release will be reduced because the time length will be shortened. Figure 5 illustrates the impact of a change in the expected time length until the food crisis is at the breakeven ratio for different values of $\varkappa_2$. The sooner the crisis starts and the sooner the crisis ends, the lower the breakeven ratio.

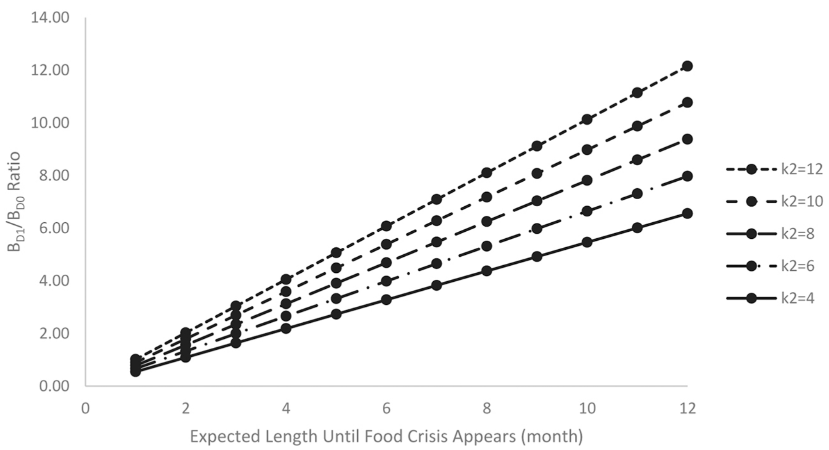

Figure 5: Effect of expected time length until food crisis occurs on B_{D1}/B_{D0} ratio.

4 Conclusion

The comparison of the two policies shows that a stockpiling policy requires substantial benefits from distributing food during a food crisis. Hence, the food crisis needs to be extremely severe. The results further show that stockpiling can be a very expensive policy. Investing in infrastructure that allows restocking storage facilities during a food crisis as well as other means seem to be more efficient solutions as suggested in the literature (e.g. von Braun 2009). In particular, policies supporting openness to trade can be an effective strategy. In this case, the government would not intervene and not face additional costs as under Policy B relying on the market system to respond to changes in food prices via imports. The results of this contribution show that this is indeed a strategy that would even be more cost-effective and might be the result of Policy B in the longer-run, with Policy B being an intermediate step. Governments first abolish food storage policies and replace these with a policy of intervention when prices increase beyond a critical level by sourcing domestically and importing, but still maintain control. As this includes imports, food trade may over time become more strongly institutionalized via market participants, and be less in need of government intervention. Hence, Policy B will still be in place but less necessary over time. Such a strategy also has the potential to increase forward and backward linkages, further stimulating economic development and reducing the possibility of a food crisis. On the contrary, policies reducing international trade in food commodities increase the possibility for a food crisis.

One of the modelling results is that the sooner the crisis starts and the sooner the crisis ends the lower the trade-offs are between Policy A and Policy B. In this case the differences are less pronounced between the two policies. In particular Policy A comes closer to an open trade policy, as more immediate response will be required. Again, stressing the importance of trade.

The results further cast doubt on the economic benefits of food storage policies. Still, we observe many countries employing such types of policies, indicating other benefits related with such policies such as political stability and power (Timmer 2010). The policy crises following the increase in food prices in 2007 to 2010 are an indication for these type of benefits, but also other kind of food policies (Wesseler et al. 2017). The reluctance of African countries to accept food aid, because the grain donated was genetically modified is one among several similar examples (Paarlberg 2008). The debate about the introduction of Vitamin-A enriched rice is another example (Dubock 2019).

Nevertheless, there are serious doubts whether political unrest can be explained by increases in food prices only. Often, many other factors are more relevant and an increase in food prices was purely the trigger (Heady, Malaiyandi, and Fan 2009). This can cause problems for food policies. If governments blame increases in food prices as the cause of political unrest, responses will be different than if they acknowledge their own failure in addressing issues raised by public protest.

Appendix

A Appendix

Table 3: Scenario results used in Figure 4.

κ_1	κ_2	κ_f	r	B_{D1}	B_{D0}	Ratio	κ_1	κ_2	κ_f	r	B_{D1}	B_{D0}	Ratio
12	**4**	2	*0.84*	*28.80*	*−1.59*	*−18.13*	12	4	2	*0.73*	*18.58*	*−1.06*	*−17.45*
12	5	2	*0.67*	*28.80*	*−3.61*	*−7.97*	12	5	2	*0.58*	*18.58*	*−4.31*	*−4.31*
12	6	2	*0.56*	*28.80*	*−9.96*	*−2.89*	12	**6**	2	0.49	18.58	30.10	0.62
12	7	2	0.48	28.80	25.89	1.11	12	7	2	0.42	18.58	4.43	4.20
12	8	2	0.42	28.80	4.97	5.80	12	8	2	0.37	18.58	2.29	8.11
12	9	2	0.37	28.80	1.99	14.46	12	9	2	0.32	18.58	1.31	14.18
12	10	2	0.34	28.80	0.56	51.82	12	10	2	0.29	18.58	0.66	28.35
12	11	2	0.31	28.80	−0.43	−67.52	12	11	2	0.27	18.58	0.13	138.25
12	12	2	0.28	28.80	−1.21	−23.76	12	12	2	0.24	18.58	−0.32	−58.53
12	16	2	0.21	28.80	−3.65	−7.89							
12	4	2	*0.66*	*13.76*	*−1.08*	*−12.79*	12	4	2	*0.56*	*9.22*	*−3.01*	*−3.07*
12	5	2	*0.52*	*13.76*	*−12.04*	*−1.14*	12	5	2	0.44	9.22	5.34	1.73
12	6	2	0.44	13.76	5.45	2.53	12	6	2	0.37	9.22	2.76	3.34
12	7	2	0.37	13.76	2.74	5.02	12	7	2	0.32	9.22	2.08	4.44
12	**8**	2	0.33	13.76	1.83	7.53	12	8	2	0.28	9.22	1.69	5.45
12	9	2	0.29	13.76	1.28	10.74	12	9	2	0.25	9.22	1.41	6.55
12	10	2	0.26	13.76	0.87	15.89	12	10	2	0.22	9.22	1.17	7.88
12	11	2	0.24	13.76	0.51	26.73	12	11	2	0.20	9.22	0.96	9.62
12	12	2	0.22	13.76	0.20	69.12	12	**12**	2	0.19	9.22	0.76	12.10

Note: Italic values are results not to be considered as r > k_f. Bolded numbers indicate the initial expected time length of the food crisis used for the calculation of B_{D1}.

Notes

1 The model resembles the one by Megiddo et al. (2019) who investigate the benefits and costs of stockpiling antibiotics in case of an influenza outbreak. The difference here is that, when food is distributed prior to a food crisis, restocking is required, which is costly and uncertain in time length, which is not the case in the study on antibiotics.
2 The term needs to be less than zero to ensure that benefits depreciate.

3 Additional information deriving the solutions are available upon request from the author.

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