

Food Security and Storage in the Middle East and North Africa

Donald F. Larson

Julian Lampietti

Christophe Gouel

Carlo Cafiero

John Roberts

The World Bank
Development Research Group
Agriculture and Rural Development Team
April 2012



Abstract

In times of highly volatile commodity markets, governments often try to protect their populations from rapidly-rising food prices, which can be particularly harsh for the poor. A potential solution for food-deficit countries is to hold strategic reserves, which can be called on when international prices spike. But how large should strategic stockpiles be? This paper develops a dynamic storage model for wheat in the Middle East and North Africa (MENA) region, where imported wheat dominates the average diet. The paper uses the model to analyze a strategy that sets aside wheat stockpiles, which

can be used when needed to keep domestic prices below a targeted price. This paper shows that if the target is set high and reserves are adequate, the strategy can be effective and robust. Contrary to most interventions, strategic storage policies are counter-cyclical and, when the importing region is sufficiently large, a regional policy can smooth global prices. This paper shows that this is the case for the MENA region. Nevertheless, the policy is more costly than the pro-cyclical policy of a targeted intervention that directly offsets high prices with a subsidy similar to food stamps.

This paper is a product of the Agriculture and Rural Development Team, Development Research Group. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at <http://econ.worldbank.org>. The author may be contacted at DLarson@worldbank.org.

The Policy Research Working Paper Series disseminates the findings of work in progress to encourage the exchange of ideas about development issues. An objective of the series is to get the findings out quickly, even if the presentations are less than fully polished. The papers carry the names of the authors and should be cited accordingly. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the International Bank for Reconstruction and Development/World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank or the governments they represent.

Food security and storage in the Middle East and North Africa*

Donald F. Larson, Julian Lampiatti, Christophe Gouel,
Carlo Cafiero and John Roberts

Keywords: food security, Middle East and North Africa, food security, price volatility, storage, strategic reserve, wheat.

JEL classification: F1, O13, Q11, Q18.

Sector Board: Agriculture and Rural Development

* Donald F. Larson, Development Research Group, World Bank; Julian Lampiatti, Middle East and North Africa Sustainable Development Department, World Bank; Christophe Gouel, Centre d'Etudes Prospectives et d'Informations Internationales and the World Bank, Carlo Cafiero, Statistics Division, FAO; and John Roberts, University of Maryland.

Food security and storage in the Middle East and North Africa

**Donald F. Larson, Julian Lampietti, Christophe Gouel,
Carlo Cafiero and John Roberts**

High and volatile food prices, and their consequences for the poor, have revived concerns about food security and reinvigorated the debate about the role of strategic storage. For the second time in three years, food prices on international markets spiked in 2011, driven in part by rising wheat prices. For the first time in more than a decade, the real price of US wheat exports (adjusted to 2000 prices) breached the \$200/ton threshold in July 2007 on its way to a high of \$352/ton in March 2008 (Figure 1). International food prices fell sharply toward the close of 2008, wheat prices among them. By June 2010, wheat prices fell to \$131 per ton, only to double within the year. Estimates suggest that the 2011 food price spike pushed 44 million people into poverty (World Bank, 2011a). Worst hit were countries that imported most of their food and the poor whose diets relied heavily on staple grains.

This is the case for many of the countries in the Middle East and North Africa (MENA) region. Diets there depend heavily on wheat that is largely imported (Table 1).¹ For example, between 2005 and 2007, Libya imported 98 percent of its wheat consumption and wheat generated 40 percent of the calories in the average Libyan diet. In Algeria, the comparable numbers were 69 and 46 percent. Consequently, spikes in international wheat prices can create hardship for the region's poor and strain the resources of the public and private institutions that make up the region's social safety net. To make matters worse, associated bouts of market volatility have made it difficult for households and governments to plan ahead.

The recent periods of high and volatile food prices have prompted proposals for policies that use commodity storage as an instrument. For example, French President Nicolas Sarkozy, when laying out an agenda for the French presidency of the G20, suggested that subsidized storage might be one way of mitigating volatile food prices (Hall, 2010). During his tenure as Director General of the International Food Policy Research Institute, Joachim von Braun promoted the use of real and virtual food inventories to dampen food price volatility (von Braun and Torero, 2009). And in a Financial Times Op-Ed piece, World Bank President Robert Zoellick urged the establishment of small strategic reserves of food in disaster-prone areas (Zoellick, 2011). The build-up of strategic reserves is also a key topic in the Middle East and North Africa (World Bank, 2009; Lampietti et al., 2001, Wright and Cafiero, 2011).

¹ For the purposes of this paper, the MENA region includes Algeria, Bahrain, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Saudi Arabia, Syria, Tunisia, United Arab Emirates, and Yemen.

Just as wheat is an important commodity for the region, MENA is an important region for the global wheat market. Between 2008 and 2010, an average of more than 29 percent of all exported wheat was destined for a country in the region. Over the last decades, countries in MENA have added to their capacity to store grains and wheat stocks have grown along with populations and demand. Precautionary policies led to an increase in the stock-to-use ratio as well, concentrating a greater share of global stocks in the region (Figure 2). From negligible levels in 1970, the region now holds more than 13 percent of global wheat stocks, an amount equivalent to 15 percent of global wheat trade and 52 percent of MENA imports (USDA, 2011, based on 2008-10 averages). Consequently, decisions taken by the region about strategic stores of wheat are of increasing importance for global markets. Moreover, with the expansion of domestic production constrained by available land and water resources, and with significant population growth projected in MENA, the region's influence on global wheat markets is expected to grow.

In this paper, we examine whether stockpiles of wheat in the region could be used strategically to ameliorate the effects of sharp run-ups in international wheat prices. Using a numerical model of competitive storage under rational expectations, we examine a strategic storage rule designed to insulate the region from the most severe price spikes, those that fall in the top 10 percent of the range of simulated prices.² We find that the strategy can reduce the variability of domestic wheat prices and blunt the domestic impact of increases in global prices. In contrast to most policy approaches that countries use to insulate themselves from off-shore price disturbances, the strategy has positive spillover effects, reducing global price variability rather than increasing it. However, the strategy will sometimes fail, when consecutive negative supply shocks occur and MENA inventories are dissipated. The frequency of failure declines as larger inventories are held, but the costs of the strategy increase as well. By comparison, a pro-cyclical relief program that targets up to 40 percent of the population is a less expensive alternative.

Background

Poverty is at the core of the region's concerns about food security. About one-quarter of the population in MENA countries is poor and about three-quarters of these poor people live in rural areas (World Bank, 2009).³ Poor households in the region spend anywhere between one-third and two-thirds of their income on food, so they are hardest hit by food-price shocks. In addition, since a relatively high concentration of the population lives on incomes near the poverty line in the region, small increases in the cost of living can have a very large impact on the incidence of poverty (World Bank, 2009).

² The term competitive storage means that grain is held with the expectation of a profit and that competition among inventory holders limits profits to normal risk-adjusted rates of return. The condition is spelled out more rigorously in a later section describing the conceptual model.

³ Poverty calculations are based on national poverty criteria.

The combination of diets heavily reliant on wheat and wheat supplies dependent on imports means that events in global wheat markets play an outsized role for welfare outcomes in the region, and this link between international markets and domestic welfare will likely strengthen with time. Population growth in MENA is projected to be 1.7 percent per year, significantly higher than the world rate of 1.1 percent (World Bank, 2009). At the same time, the potential for expanding supplies on irrigated lands is severely constrained; per capita water availability is projected to fall by half by 2050, with serious consequences for the region's already stressed aquifers and natural hydrological systems (World Bank, 2007). As a consequence, projections of the region's food balance indicate that imports will increase by almost 64 percent over the next twenty years (World Bank, 2009).

When price shocks occur, governments often intervene. In MENA, the interventions come in many forms, but consumer subsidies are the most favored instruments (Lampietti et al., 2011). For example, in Tunisia, Jordan, Morocco, Egypt, Syria, and Iraq, where disaggregated data are available, food subsidies averaged 1.6 percent of GDP in 2009 and totaled \$8.1 billion (World Bank, 2011c). More recently, and in response to high food commodity prices and popular uprisings, many governments have expanded consumer subsidies, likely contributing to significantly higher costs.

At the same time, the capacity of governments to shore up safety net programs against high food prices differs among countries in the region (World Bank, 2009, 2011c). All else equal, countries with large fiscal deficits and high cereal import dependency are least able to absorb a wheat price shock. These are mostly the oil importers (Jordan and Lebanon) and the region's developing oil exporters (Yemen, Iraq and Syria). In contrast, the Gulf Cooperation Council (GCC) countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates) have ample budgetary resources to absorb higher costs, even though they are entirely dependent on the international markets for their wheat. Moreover, in these countries rising food import bills are frequently offset by rising export revenue, because of the positive correlation between energy and food prices. Egypt and Morocco do not have the luxury of ample fiscal space to absorb sustained higher prices, although their higher domestic production levels help cushion price shocks.

Despite the preponderance of consumer subsidies, evidence suggests that international food price shocks are nonetheless transmitted to various degrees to domestic food prices throughout the region (World Bank, 2011c). Over a five year period ending in February 2011, domestic food prices rose, on average, by more than 10 percent annually in Egypt, Iran, and Yemen, and by nearly 5 percent or more in Djibouti, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia and the United Arab Emirates.⁴ Rising world food prices have been a major factor behind increases in domestic food prices, typically explaining some 20 to 30 percent of the

⁴ Average annual food price rates of increase are based on 60 months of data, with the following exceptions: 58 months of data was used for Lebanon, and the West Bank and Gaza; and 57 months were used for Yemen.

variation in domestic prices.⁵ International price changes have been particularly strong drivers of food inflation in Iraq and West Bank and Gaza, accounting for over 50 percent of the food inflation, followed by Egypt, Djibouti and the United Arab Emirates (over 40 percent of the food inflation). Except for Tunisia and Algeria, exchange rate depreciation has been a minor factor in domestic food inflation. The pass-through is smaller but is still sizable, varying between 0.2 and 0.4 percent, for a large group of MENA countries, including Morocco, Jordan, Syria, Iran, Yemen, and all GCC countries other than United Arab Emirates. This indicates a high degree of vulnerability of households to international food price increases in virtually all MENA countries.

Over the past 50 years, most countries, even those that actively intervene in food markets, have come to depend on private markets for the physical distribution of food (Akiyama et al., 2001). This is less true in MENA, where governments often play a significant role in the procurement, storage, and distribution of wheat. And many countries have explicit policies determining the level of strategic reserves the government is required to have on hand at any given time. Overall, storage capacity in the region is on average six months of consumption and estimated ending stocks are five months (World Bank, 2012). Plans are already well underway to expand storage capacity in selected countries by an additional 5 months on average.

While there are different levels of private participation in wheat storage and distribution in the region, recent analysis suggests that the costs of port logistics, storage, inland transport (to the mills) and management are on average \$42 per metric ton of wheat or 12.5 percent of the cost of a ton of wheat at current prices. The largest components of these costs are port logistics (\$13 per metric ton) and management (\$14 per ton), which includes such costs as product loss, cost of capital, and overhead. The average cost of storage for the region ranges between \$1.5 and \$3.5 per metric ton per month, which compares favorably with storage costs in the Netherlands and the United States, both large handlers of traded grain, where storage costs run about \$2.00 per metric ton per month (World Bank, 2012).

Wheat consumption rates are high in MENA, and because of the large government presence in domestic markets, wheat price shocks have important budgetary consequences. The World Bank (2011c) estimates that the rise of food prices in MENA in 2010 increased the import bill by 0.6 percent of GDP with grains making the largest contribution, followed by edible oils, sugar and meat. Oil importers are expected to be hardest hit with an estimated increase in the import bill of 1.2 percent of GDP, and with half of the increase attributed to the impact of higher grain prices. The expected increase in the import bill of the developing oil exporters as a result of higher food product prices is estimated at 0.8 percent of GDP with grain accounting for slightly less than half the increase.

⁵ Based on calculated pass-through rates (World Bank, 2011c).

Commodity stabilization policy experience

To a large degree, policy makers view strategic stores of commodities as a buffer against unusual and unanticipated disruptions to normally dependable commodity markets. However, there was a period, spanning several decades following the end of World War II when policy makers sought to manage commodity prices and the export earnings of commodity-producing countries, often through public management of stockpiles or through related financing instruments. The policies were much discussed and studied, so there is a large literature on the motivation and workings of public inventory schemes.⁶ In this section we provide a brief review of past ideas and outcomes, which are worth keeping in mind as future roles for strategic inventories are considered.

A conceptual motivation for this class of price-management policies was formalized in Massell (1969; 1970), who compared a linear market model with and without additive mean-zero supply or demand disturbances and concluded that commodity price stabilization could generate welfare benefits that could be shared among producers and consumers. Wright (1979) confirmed, in a rational expectations model, that this positive result following an “ideal stabilization” is a possibility, depending on the type of disturbance, demand curvature and supply response. Use of stocks for stabilization had no similar analytical backing, but had gained favor internationally much earlier, from economists as diverse as Hayek (1943) and Keynes (1938). Low commodity prices were seen as an exacerbating factor in the Great Depression, and the feasibility of public management of commodity supply chains was demonstrated by country experience during World War II. Between 1954 and 1980, treaties between the major producing and consuming countries resulted in five international commodity agreements with price stabilization mechanism components. Three of the agreements, for tin, cocoa and rubber, relied on managed buffer stocks to smooth international prices. National governments launched domestic stabilization programs as well. The European Union, Japan, and the United States all employed government-controlled inventories to help manage commodity prices, and buffer stock schemes were launched in Bangladesh, India, Indonesia, the Republic of Korea, Mexico and the Philippines. In 1969, the IMF established a Buffer Stock Financing Facility to provide lending support to the stabilization efforts. The Common Fund for Commodities was established to provide liquidity to international stabilization programs under a UN initiated Integrated Program for Commodities established to stabilize the prices of ten core commodities in 1975 (Larson et al., 2004; Knudsen and Nash, 1990).

A series of conceptual and empirical studies emerged to suggest that average welfare gains from stabilization were small relative to changes in average price levels (Newbery and Stiglitz, 1981; Anderson et al., 1981; Myers and Oehmke, 1988). In a series of pioneering papers and a subsequent volume, Williams and Wright (1991) explored the interactions of public and private stocks. Their work and related studies showed that that,

⁶ See Larson, Anderson and Varangis (2004) for a more complete review.

because of resource limits, stabilization schemes are subject to eventual bankruptcy, even when they are rationally priced and hedged in financial markets when unlikely events eventually occur (Wright 1979; Wright and Williams 1982, 1984, 1988; Larson and Coleman, 1993). Choosing an appropriate price to defend is another difficulty faced by stabilization program managers and this technical hurdle was heightened by political economy problems that often converted stabilization programs into programs that defended unreasonably high price levels or taxed producers (Bauer and Paish, 1952; Bardsley, 1994).

More convincing for policy makers were the insurmountable practical difficulties of implementing the stabilization mandate once the policies were in place. Even well-run stabilization schemes faced large technical problems and many failed, sometimes in spectacular fashion, greatly depressing the markets they were designed to stabilize.⁷ By the 1990s the stabilization component of the international commodity agreements were no longer in force and Gilbert (1996) provided an obituary notice.

As theoretical and practical objections grew for policies aimed at managing prices, a separate literature emerged on the consequences of commodity risks for vulnerable households and governments. This large literature centered on the role of risk-mitigation and adaptation strategies, rural livelihoods and forms of formal and informal insurance. Larson, Anderson and Varangis (2004) and Dercon (2005) provide reviews. Topics related to storage and trade are relevant here as well, since both informal mechanisms and formal market mechanisms, including storage markets, work to automatically smooth prices and incomes.

There is a widely held view that relying on trade and private storage is usually much more efficient than relying on government inventories to buffer normal demand and supply shocks, since world markets have the potential to diversify away volatility by pooling risks across many countries (see Dorosh, 2008, for a recent discussion). However, this can change when physical disruptions occur that isolate supplies from demand – for example disruptions from armed conflicts and lawlessness, sovereign risks, including trade disruptions, or logistical disruptions. It is perhaps most common to think of disruptions of this type as occurring at national borders; however, logistical constraints to providing food in response to harvest shortfalls in remote areas present a similar problem. For this reasons, countries and food relief agencies invest heavily in understanding the logistics of domestic food delivery systems (Thomas and Fritz, 2006; Van Wassenhove, 2006).

Though strategic and precautionary public stores are often a key component of food security programs, there are surprisingly few empirical studies that examine the cost tradeoffs between strategic storage and trade.⁸ Instead, most strategic storage papers deal primarily with political and national security issues, often in the context of game theory and petroleum reserve. See, for example, Victor and Eskreis-Winkler (2011), Fan and

⁷ See, for example, Yamey's (1992) description of the collapse of the tin stabilization fund and its consequences for the London Metals Exchange, or Bardsley's (1994) description of Australia's Wool Reserve Price Scheme.

⁸ Exceptions include Srinivasan and Jha (2001), Brennan (2003), and Gouel and Jean (2012).

Zhang (2010) and references therein. This creates a knowledge gap for policy makers, since other forms of investment, including investments that improve trade corridors or expand irrigation, can be viewed as partial substitutes to investments in public storage. A benefit of the model discussed here is that it can be used to evaluate the effects of more reliable production or lower transaction costs on price levels and price volatility.

The model

In this section we describe the model that we use to assess the effects of strategic storage policy on domestic prices in the MENA region and the rest of the world (RoW).⁹ The intuition behind the model is that physical storage and the equilibrium price of physical storage sits at the cusp of spatial and temporal arbitrage possibilities. Decisions about selling today for consumption or trade must be balanced against the known cost of storing and probable future prices. Expectations about the future value of stored goods are conditional, based on information available at present time, which in this particular model is summarized by inventory levels. In particular, all things equal, price outcomes are more likely higher and more volatile when initial inventories are low.¹⁰ This is because, when stocks are low, outcomes in which production short-falls are rationed through high-prices rather than buffered through stock draw-downs are more probable.

A key feature of the class of models, including the one presented here, is the need to form a rational set of numerical price expectations, conditional on the parameters of the model and information available at that time, in order to value carry-over inventories and future production.¹¹ Specifically, the model uses a set of spatial and temporal price arbitrage conditions, together with assumptions about demand and supply, and about the distribution of supply shocks to model the distributions of price and consumption outcomes. With these as a baseline, policies are introduced that are meant to change price outcomes, and the consequences of the policy interventions on the distribution of prices and consumption are evaluated. It is worth emphasizing that the model is not a forecasting tool, but rather a way to evaluate strategic storage rules on price and consumption levels and volatility.

⁹ The trade-and-storage model was first developed in Williams and Wright (1991, Ch. 9), and was subsequently analyzed in Miranda and Glauber (1995), and Makki, Tweeten and Miranda (1996).

¹⁰ Wright and Williams (1982) show that the possibility of a stock-out is sufficient to generate this effect. Drawing on Working (1948), Makki, Tweeten and Miranda (1996) generate a similar outcome by introducing a convenience yield that increases with declining stocks. Considine and Larson (2001) show that this type of outcome is possible in the case of a commodity without seasonal production if short-run marginal costs have the expected curvature, increasing at increasing rates. Larson (2007) derives the temporal and spatial arbitrage conditions for the model analytically and shows that non-linearities in the interaction of supply and demand are sufficient.

¹¹ Gustafson (1958) provided early insights about the link between rational expectations and the price of storage. He also pioneered an approach for solving a restricted version of the model using paper and pen. Gardner (1979) built on Gustafson's analytic work and also adapted Gustafson's algorithm for use in a computer program. This later served as the basis for an improved version of the algorithm by Wright and Williams (1982).

Model equations

More formally, the model can be characterized with the following set of relationships. Current consumption in region i , where $i \in \{\text{MENA, RoW}\}$, is given by a downward sloping function of current price:

$$D^i(P_t^i) = a^i - b^i P_t^i, \quad (1)$$

where P_t^i is the price of wheat in period t and region i .

In each region, there is a representative storing agent that acts competitively and incurs the following cost for storing an amount S_t^i from period t until $t + 1$:

$$K(S_t^i) = (1 + r)(kS_t^i + P_t^i S_t^i), \quad (2)$$

where $k \geq 0$ is the net unit cost of physical storage services, r is the interest rate, and both are assumed to be identical in the two regions. Accounting for the non-negativity constraint on storage, the first-order condition of the storer's problem yields the following complementarity condition¹²

$$S_t^i \geq 0 \perp P_t^i + k - E_t P_{t+1}^i / (1 + r) \geq 0, \quad (3)$$

where E_t denotes the mathematical expectations operator conditional on information available at time t . This implies that storage occurs when there is an expectation that the returns to storage, net of the time value of money and physical storage costs, are positive. It should also be emphasized that the evaluation is based on an expected price for period $t + 1$. The formulation of this expectation is a key aspect of the numeric model.

Production is uncertain in the model. Representative producers make their production choices and pay for inputs one period before bringing output to market. We represent that choice, made in period t , as planned production, \bar{H}_t^i . Actual and realized production differ by a multiplicative exogenous disturbance term, ε_{t+1}^i , centered on one, so that stochastic revenue is defined as $P_{t+1}^i \bar{H}_t^i \varepsilon_{t+1}^i$. The producer's choice is based on information and input prices in period t and can be written as:

$$\max_{\bar{H}_t^i} E_t (P_{t+1}^i \bar{H}_t^i \varepsilon_{t+1}^i) / (1 + r) - \Psi^i(\bar{H}_t^i), \quad (4)$$

where ε_t^i is normally distributed with a mean of 1 and a variance of σ_i^2 ; $\Psi^i(\bar{H}_t^i)$ is the production cost corresponding to the planned production. The solution of this problem is the following equation

¹² The “perp” notation (\perp) used in the complementarity condition means that the expressions on either side of the sign are orthogonal, so that if one equation holds as strict inequality, the remaining side holds as a strict equality. In cases with two bounds, the expression $a \leq X \leq b \perp F(X)$ is a compact formulation for $X = a \Rightarrow F(X) \geq 0, X \in]a, b[\Rightarrow F(X) = 0, X = b \Rightarrow F(X) \leq 0$.

$$E_t(P_{t+1}^i \varepsilon_{t+1}^i) / (1+r) = \Psi^i(\bar{H}_t^i). \quad (5)$$

Note from equation (5) that, contrary to storing agents, producers do not base their production plans on price alone, but consider marginal expected revenue, which includes an expectation about prices and the likelihood of price-correlated production surpluses or shortfalls.

Differences between production, consumption and storage in either location are balanced by trade. We assume that wheat is a homogeneous product, so that trade is decided by the spatial arbitrage condition:

$$X_t^i \geq 0 \perp P_t^i + \theta \geq P_t^j \text{ for } j \neq i, \quad (6)$$

where X_t^i is the export from region i , and θ is the per-unit transaction cost, inclusive of transport costs. For the problem at hand, we assume that transaction costs are constant over the relevant time horizon and do not depend on the direction of trade,¹³ so that prices in MENA fall within a moving band that is defined by the RoW price and trade costs:

$$P_t^j - \theta \leq P_t^i \leq P_t^j + \theta \text{ for } j \neq i. \quad (7)$$

At any point in time, three predetermined variables per country define the state of the model: carry-in stocks, S_{t-1}^i ; planned production, \bar{H}_{t-1}^i ; and the period shock, ε_t^i . The latter two variables determine actual production and the three can be combined in one state variable, private availability, A_t^i , the sum of production and private carry-over:

$$A_t^i \equiv S_{t-1}^i + \bar{H}_{t-1}^i \varepsilon_t^i. \quad (8)$$

Market equilibrium can be written as

$$A_t^i + X_t^j = D^i(P_t^i) + S_t^i + X_t^i \text{ for } j \neq i. \quad (9)$$

To summarize, the numeric problem has two state variables, $\{A_t^{\text{MENA}}, A_t^{\text{RoW}}\}$, and eight response variables, $\{P_t^i, S_t^i, H_t^i, X_t^i\}$ for $i \in \{\text{MENA}, \text{RoW}\}$. Solutions follow a dynamic path since stocks are carried from one period to the next.

Calibrating the model and finding a numerical solution

The parameters for the model are chosen such that, at the non-stochastic steady-state, the equilibrium reproduces the physical trend of the world wheat market in 2011 (Table 2). We can see that for this calibration, the MENA region is a significant net importer, with imports of around 47 percent of its consumption. For the steady-state prices, we decide not to rely on 2011 values, which are very high by

¹³ In practice, the MENA region does not export wheat, so the assumption of symmetric trade costs is innocuous

historical standards, since it is unlikely that the steady state is associated with extreme values. Therefore, we calibrate the rest of the world price at \$176/ton, the average US export price in 2005—2007, a period before the very high prices of the food crisis but during a time when prices were higher than in the beginning of the decade.¹⁴ The steady-state MENA price is defined by assuming that the price difference between the regions reflects transport costs, which is set at \$35.55/ton based on a recent survey (World Bank, 2012).

Picking appropriate elasticities is a challenge given the large variation in elasticities reported in the literature. As a guide, we follow the literature on commodity price dynamics, which shows that observed price volatility is consistent with relatively low demand elasticities (Roberts and Schlenker, 2009; Cafiero et al., 2011), thus, we assume the demand elasticity to be equal to -0.12 , which is toward the lower end of commonly used elasticities. We consider a supply elasticity of 0.2 , in line with commonly used supply elasticities for wheat.¹⁵ The cost function is assumed to be quadratic, making the marginal cost function linear. We express the marginal cost function as

$$\psi^i(\bar{H}_t^i) = c^i + d^i \bar{H}_t^i. \quad (10)$$

The parameters c^i and d^i determine the supply elasticity (see Table 2) assuming that marginal cost equals the steady-state price.

We specify two sets of uncorrelated supply shocks, $\varepsilon^i \sim N(1, \sigma_i^2)$. Based on historical production data, we derive an estimated distribution of supply shocks, where production in MENA is more volatile than in the rest of the world.

Interest rates and per unit storage charges are assumed to be the same for each region at 5 percent per annum and \$22.40 per ton per annum. The storage costs are based on recent findings in a World Bank study on wheat markets in MENA (World Bank, 2012).

The rational expectations storage model is known to lack a closed-form solution and so has to be approximated numerically. The numerical algorithm that we use is based on a projection method inspired by Miranda and Glauber (1995) and is described in detail in Gouel and Jean (2012, Appendix D).¹⁶

¹⁴ Average annual prices are for wheat (US), no. 1, hard red winter, ordinary protein, export price delivered at the US Gulf port for prompt or 30 days shipment as reported by the World Bank (2011b).

¹⁵ See, for example, FAPRI's elasticity database, available on the internet at <http://www.fapri.iastate.edu/tools/elasticity.aspx>.

¹⁶ A description of the solution algorithm and solver written for MATLAB is freely available on <https://github.com/christophe-gouel/recs>.

Calibrated model behavior

Recall that the model is calibrated around a set of prices and quantities, together with two distributions of supply shocks that the model randomly draws on in simulation. Because of this structure, the mean values of the simulated series will be near their calibrated values. However, the variations in the simulated variables are affected by the sets of randomly drawn supply shocks. Because these distributions are not specified directly, we use the ex post variability in the simulated distributions of price, demand, supply and trade as to provide a validation check on the aggregate consequences of our ex ante parameter selections. With this as background, the simulated and historical coefficients of variation are reported in Table 3. As the table makes clear, orders of magnitude are similar between the historical and simulated distributions.

As emphasized in our earlier discussion of the link between storage and price expectations, all other things equal, low inventories should be associated with both higher expected price and more volatile price outcomes. This relationship is evident in Figure 3, which maps next-period simulated prices and expected prices against carry-in stock levels. Expected prices rise as carry-in inventories fall and the model-generated prices become more dispersed.

Before moving to a discussion of alternative policies, a couple of points should be made about trade and storage outcomes in the baseline model. First, given the large gap between production and demand in MENA, the simulated model never generates an outcome in which wheat is exported from the region. This is consistent with expectations since MENA has not been a net exporter of wheat in the last fifty years.

The second point has to do with speculative storage—that is, storage that is held in order to profit from expected temporal price changes. Data series, including the data reported in Figure 2, contain all forms of storage: speculative storage, public storage, and pipeline storage that is needed to keep shipping and processing operations running smoothly. It is impossible to isolate speculative storage in the data; however, it is speculative storage that is key to the model's pricing mechanics. Conceptually, when one country is a perpetual importer, speculative storage will always take place in the exporting country, absent physical impediments to trade, large differences in physical storage costs or changing transfer costs (Gouel and Jean, 2012). This is because an importing speculator pays interest on the costs of importing in addition to interest on the price of the commodity, a cost that a speculator in an exporting country does not have to pay. Unless there is an offsetting benefit to storing locally, competition will result in adjustments in trade rather than storage in response to changes in availability in the importing country.¹⁷ This general finding applies to our model outcomes as well, and speculative private storage always takes place in RoW.

¹⁷ The result also depends on the assumption that trade is instantaneous in our model. If trade takes time, it is rational to store while importing in order to be able to wait for the next shipment (Coleman, 2009). In a related way, variations in production generate greater price variability in landlocked and isolated countries (Byerlee, Jayne and Myers, 2006).

Strategic storage

In this section, we describe a regional cooperative strategy, where strategic inventories of wheat are held in MENA as a hedge against high global prices. In keeping with our earlier discussion, the objective of the cooperative strategy is to mitigate the consequences of price spikes, that is, brief periods of exceptionally high prices like those experienced in 2008 and 2010. Government interventions are designed to be rare in order to manage the costs of the program, which include the costs associated with displacement of private storage by costly government storage.

As discussed, there is no speculative storage in the MENA region in the benchmark model. However, we assume that MENA governments hold strategic reserves, which are not directly available for consumption unless released by managers of the strategic reserves, who follow strict rules. Furthermore, we assume that the goal of the strategy is to stabilize domestic prices rather than to directly influence global prices; a practical implication is that exports are prohibited when stocks are released.

Three inter-related components are needed to fully define the public intervention. The first has to do with the maximum domestic price the strategy hopes to defend. As discussed in an earlier section, most programs designed to stabilize domestic or international prices through the build-up and release of strategic stock-stabilization are prone to failure because they set out to defend unrealistic price goals. What's more, even when goals are set reasonably, inventories are depleted when rare but eventual combinations of events occur, for example, consecutive bad harvests. With this in mind, we have chosen a conservative strategic reserve objective for our simulation. Based on the benchmark model, we simulated the range of MENA price outcomes and from the resulting set of prices, picked the last decile—that is, the minimum price that is above 90 percent of the simulated price outcomes; this works out to be \$263 per ton. Importantly, by choosing to intervene at the 90th percentile, the policy insures that interventions will be rare. It is also the case that, because the policy targets a thinning portion of the probability density function, most price outcomes above-the-trigger are expected to cluster near the target price. To summarize, choosing the 90th percentile means that most strategic interventions will occur when prices are slightly above the target price, and conversely, large gaps between world prices and the target price will be rare.

A second decision sets the desired size of the strategic reserve, the target storage goal. This decision affects the robustness of the strategic policy because, when high prices do occur, domestic prices can only be lowered if there are sufficient supplies of wheat to be released from storage. When stocks are exhausted, domestic prices can rise above the target level. Said differently, the program fails less frequently as the size of the government's strategic reserve increases.

The third decision relates to how aggressively MENA wants to build toward its target storage goal. When the domestic price is below the price threshold and strategic inventories are below the target storage goal, MENA

will add inventories at a given rate. Logistical capacity constraints will likely limit the rate of build-up, and there may be additional factors as well, for example a desire to spread the cost over multiple fiscal years. A larger build-up rate reflects a more aggressive storage strategy and results in a faster recovery when stocks are drawn down. A lower rate spreads out the buying and buildup of stocks over a longer time period and diversifies price risk.

The decision rules can be written out more formally as follows. The rules to build stocks or release them can be summarized by the following complementarity equation:

$$0 \leq S_t^G \leq \bar{S}^G(S_{t-1}^G) \perp P_t^{\text{MENA}} - P^C, \quad (11)$$

where S_t^G is the public storage level in MENA; P^C is the price ceiling; and $\bar{S}^G(S_{t-1}^G)$ is a capacity constraint in period t that public storage cannot exceed. This public storage behavior is accounted for by other agents and affects their expectations. Accordingly, we have to modify some equations from the previous model to accommodate public storage. In contrast to equation (9) in the benchmark model, market equilibrium in this situation takes the following form:

$$S_{t-1}^G + A_t^{\text{MENA}} + X_t^{\text{RoW}} = D^{\text{MENA}}(P_t^{\text{MENA}}) + S_t^{\text{MENA}} + S_t^G. \quad (12)$$

As discussed, wheat exports never emanate from MENA in the benchmark model even though they are not explicitly constrained. This helps us simplify our equilibrium specifications in the strategic reserve model. To prevent released strategic reserves from being exported, we suppress MENA export equation (equation (6) for $i = \text{MENA}$ in the benchmark model), and MENA exports from rest of the world market equilibrium.

Mathematically, we express the restocking rule as

$$\bar{S}^G(S_{t-1}^G) = S_{t-1}^G + \alpha(\bar{S}^G - S_{t-1}^G), \quad (13)$$

where $0 \leq \alpha \leq 1$ is the build-up rate, and \bar{S}^G is the targeted size of the strategic reserve.¹⁸

Given that previous public storage level affects the current equilibrium, it plays the role of a state variable. So, when considering public intervention, the problem has three state variables, $\{A_t^{\text{MENA}}, A_t^{\text{RoW}}, S_{t-1}^G\}$, and eight response variables, $\{P_t^i, S_t^i, H_t^i, X_t^{\text{RoW}}, S_t^G\}$ for $i \in \{\text{MENA}, \text{RoW}\}$.

We are not aware of another study that has analyzed this kind of policy, although it does resemble the “price-peg” studied in the context of a single market by Salant (1983) and by Williams and Wright (1991, Ch. 14). A price-peg is a policy that defends an intervention price by accumulating stocks when price is below the intervention and by selling when price reaches the intervention. A capacity constraint limits stock

¹⁸ Given this definition, the maximum storage level can never fully reached (except if $\alpha = 1$), but is approached asymptotically.

accumulation and avoids, in this way, over-accumulation. Our policy differs from a price peg only in equation (13) which sets the rate of stock accumulation.

Simulation outcomes

Parameter interactions

As discussed, the intervention price is set high and is designed to protect against the highest ten-percent tail of the expected price distribution. Choices about the targeted size of the reserve and the rate at which it is replenished determine the robustness of the policy. For the analysis reported in this section, the model is simulated 100,000 times for each of three buying strategies (10, 50 and 100 percent replenishment rates) and a range of target inventory levels from no strategic reserves (the benchmark model) to a target reserve equivalent to 120 percent of steady-state consumption, which is equivalent to more than 2.5 years of steady-state imports. For a given starting point, outcomes depend on the realized supply shocks, and it is only by simulating over several possible sequences of shocks that probable outcomes merge to an expected trajectory. However, before delving into the aggregate results, we use an example from a single price path to illustrate how the parameters interact to affect prices.

Figure 4 shows the dynamic path of prices under three scenarios: the benchmark model where prices are determined competitively and two strategic storage regimes, one where the target reserve level is set at 20 percent of steady-state consumption and another where the reserve is set at 100 percent. In both strategic reserve scenarios the target price is set at the start of the 90th percentile and the restocking rate is set at 10 percent. The time horizon of the path covers 80 periods.

It should be emphasized that the particular path reported in the figure is illustrative and a different sequence of random shocks would evoke a different path; but the figure does provide insight into how the strategic rules interact. In the first years, stocks build. When prices are high enough to trigger a release of inventories, the gap between domestic prices and the target prices is frequently small and a partial release of stocks is sufficient to drive down domestic and international prices.¹⁹ Toward the end of the path, a large shock occurs which depletes reserve stocks, completely in the case of the smaller reserve, allowing prices to exceed the target price. An unfortunately timed second negative shock occurs before stocks can be rebuilt and the smaller-reserve policy fails again. The example yields two seemingly contradictory results that are nonetheless intrinsic characteristics of strategic reserves: the policy is capable of successfully defending a target price for many years but can fail even when reserves are large and the target price is high.

¹⁹ When stocks in MENA are released, imports into MENA are displaced. When prices are only slightly above the trigger prices, a small displacement is sufficient to bring international prices to a point where domestic prices are at the trigger price.

Stabilization results

The tradeoffs among the strategic storage rules are illustrated in Figure 5. A range of targeted reserve levels are reported along the horizontal axes of the figure's panels while variables of interest are reported on the vertical axes. The data behind the graphs is reported in Annex Table 1 and Annex Table 2.

Turning first to the two upper left-hand-side panels, simulation results suggest that the strategic reserve can be effective in lowering the overall variation in domestic prices and consumption, and that the efficacy of the policy increases as the level of strategic stores is set higher. For example, at a restocking rate of 10 percent, a targeted reserve rate of 20 percent of consumption and a target price at the 90th quantile, the strategy reduces the coefficient of variation (CV) for MENA wheat prices from 16.4 to 15.2, and reduces the CV of domestic consumption from 1.98 to 1.83. Increasing the restocking rate from 10 percent to 50 percent increases the robustness of the policy as the probability of a stockout falls from 4.4 to 2.4 percent. This, in turn, boosts the performance of the strategic reserve policy, further reducing domestic price and consumption volatility to 14.8 and 1.79 percent.

An important outcome from the model is that the strategic reserve policy, designed to protect domestic consumers, lowers the volatility of prices in the rest-of-the world as well. Indeed, a comparison of the upper and lower portions of the first panel of Figure 5 shows that, because of trade, the coefficient of variation of price in RoW evolves similarly to the CV in MENA. By design, there are periods when the stocks released under the strategy are large enough to completely displace imports into MENA. However, this occurs infrequently, partly because the targeted price is set high and is rarely breached. In fact, the full displacement of MENA imports occurs less than 0.1 percent of the time and only occurs at target storage levels of at least 30 percent of normal consumption. In very rare instances, the correlation between local and RoW prices is also re-established when the trigger is breached, but stocks are insufficient to insulate domestic consumers.

As discussed, an aggressive strategy of restocking reserves lowers the chance that sequential periods of high prices will deplete the reserves. However, while supply shocks may be uncorrelated, high prices are not since low inventory levels can persist, setting the stage for sequential periods of high prices. An aggressive restocking rate means that the reserve manager is more likely to add more reserves when international availability is tight and prices are high. Consequently, the relationship between the coefficient of variation of price and the build-up rate is not monotonic. For low reserve targets, prices are less volatile with a higher build-up rate, but the opposite is true for high target reserves. As the size of the reserve builds, the probability of a stockout falls significantly even at low restocking rates. Consequently, a more aggressive restocking policy becomes destabilizing since larger interventions reduces the quantities available for consumption and private storage, but yield only small increases in the capacity of the policy to withstand sequential periods of high prices, and therefore generate small marginal reductions in price volatility.

The effect of the policy on trade is unambiguous and generates increased rates of volatility, with the CV of trade increasing from 8.6 to 11.5 percent for a 20 percent target reserve with a 10 percent build-up rate (Figure 5, last panel). Periods of stock accumulation imply trade levels higher than the normal. And releases of stock displace imports.

Public storage also has an effect on private storage, through two channels. First, by decreasing price volatility, public storage decreases the profit opportunities from speculation and the incentive to store privately. Second, public reserves follow a predictable storage rule that can be exploited by speculators, either by running on the public stocks or by strategically dumping private reserves into the program. In the policy we examine, a run on public reserves (as in Salant, 1983) is unlikely since the intervention price is quite high. On Figure 6, the behavior of the various storage rules is illustrated. In order to draw the storage rules in a 2-dimensional figure, we are obliged to choose a situation in which the model depends only on the level of global availabilities; this is true when the build-up rate is equal to 100 percent and when MENA is always importing. We observe that private storage is significantly reduced by the policy and that private storage starts to accumulate stocks for much higher availability level under a strategic reserve program. Overall, the level of global stock increases because of the policy, but this is accomplished partly at the expense of speculative storage.

Program costs

The direct costs of the strategies are provided in the fifth panel of Figure 5, based on the following:²⁰

$$[1 - 1/(1 + r)]E_0 \sum_{t=0}^{\infty} (1 + r)^{-t} [(P_t^{\text{MENA}} + k)S_t^G - P_t^{\text{MENA}}S_{t-1}^G], \quad (14)$$

where the discount rate used to calculate costs is the same rate used to discount storage costs. It should be kept in mind that the calculation is strictly one of costs and not net benefits which ultimately depend on assumptions about risk aversion in MENA and the RoW.²¹

The annual average cost of the strategic reserve program evolves almost linearly with the targeted size of the strategic reserve. For a 10 percent build-up rate and a target at 20 percent of normal consumption, the annual cost of the policy is \$303 million. Program costs increase rapidly as the target storage goal increases, climbing to \$1,593 million for a target equivalent to one year of consumption. As discussed, the marginal stabilization benefit of increasing reserves falls quickly once the reserve target moves beyond 40 percent of consumption

²⁰ Since the program is on-going, the annualized cost is the average of an infinite sum. To calculate it, we follow the dynamic programming trick of transforming the infinite sum into a recursive problem that can be solved by value function iteration.

²¹ In general, the benefits of changes in price volatility are small relative to changes in price levels (see Newbery and Stiglitz, 1981, Ch. 14).

(87 percent of trade). A more aggressive restocking rule raises the average purchase price for the strategic reserves and this drives up program costs as well. Among the policy options presented in the Figure 5, the calculations suggest a reasonable approach would be a strategy that sets the reserve target at 50 percent of annual consumption with a restocking rate of 10 percent. This strategy is expected to reduce domestic price volatility from 16.4 to 14.5 percent, reduces international price volatility from 19.6 to 17.4, and reduces demand volatility from 1.98 to 1.74. The program is expected to fail 0.55 percent of the time and cost \$827 million per year to maintain. While the failure rate is low overall, keep in mind that because the trigger price is set at the high end of the price distribution, no intervention is required 90 percent of the time on average. Consequently, a less sanguine interpretation of this result is that the policy will fail, completely or partially, about 5.5 percent of the time interventions are required.

Targeted transfers

Often governments find it more cost effective to target the most vulnerable for assistance. The basic notion is that some portion of society can rely on its own resources even in times of high food prices, and excluding them from safety-net programs lowers program costs. With this in mind, we consider an alternative food security policy in which only a targeted group is protected during high-price periods. The alternative policy allows domestic prices to fluctuate as markets dictate, but provides direct assistance in the form of food coupons to a targeted group, permitting them to purchase wheat at the targeted price.²² Contrary to a storage policy, there are no physical inventories and the targeted program does not fail as long as the government is willing and able to fund it. Because public inventories are not stored in support of the program, costs are only occurred when prices breach the targeted price.

Before continuing, it should be pointed out that there are alternative ways of structuring targeted food safety nets.²³ There are also alternatives ways to manage the financing of safety net programs, drawing on financial risk-management instruments, including options, weather insurance or catastrophe bonds (Alderman and Haque, 2006; Mahul and Ghesquiere, 2007; Skees et al., 2005). However for our purposes, cash-equivalent transfers where the program's cost falls to the government serve as a realistic, useful and simple benchmark with which to compare program costs.

²² The program is somewhat akin to the US food stamp program. Though effective, such programs require careful implementation. See Mykerezzi and Mills (2010) and references therein for more on the impact of the US food stamp program on food insecurity.

²³ Because technological advances have lowered implementation costs, they are increasingly used in developing countries (Ahmed, 2005). But targeted food transfers are still much used, including self-targeting approaches, such as below-market-wage food for work program (del Ninno, Dorosh, Subbarao, 2007). Moreover, there are potential reasons for doing so, separate from logistical considerations. Food transfers may provide a more consistent delivery of benefits compared to cash transfers when local prices vary significantly from national averages (Sabates-Wheeler and Devereux, 2010); there is also evidence that cash transfers can raise local food prices, thereby diminishing their efficacy (Cunha, De Giorgi, Jayachandran, 2011).

In the context of the model, the market equilibrium equation for MENA under the new policy is:

$$A_t^{\text{MENA}} + X_t^{\text{RoW}} = (1 - \lambda)D^{\text{MENA}}(P_t^{\text{MENA}}) + \lambda D^{\text{MENA}}(\min(P_t^{\text{MENA}}, P^C)) + S_t^{\text{MENA}} + X_t^{\text{MENA}}, \quad (15)$$

where λ represents the share of households covered by the policy. The costs associated with implementing the identification and targeting of qualifying households is excluded, even though the costs may be very consequential.²⁴ The cost of this policy is given by:

$$[1 - 1/(1 + r)]\lambda E_0 \sum_{t=0}^{\infty} (1 + r)^{-t} [\max(P_t^{\text{MENA}} - P^C, 0) D^{\text{MENA}}(\min(P_t^{\text{MENA}}, P^C))]. \quad (16)$$

Simulation results from the alternative policy are shown in Figure 7. Because the trigger price sits at the 90th quantile, payouts occur infrequently. Moreover, because the program covers the thin tail of the price probability distribution, prices that would warrant payouts are clustered near the trigger and this keeps typical payouts low. In turn, these features keep average program costs down to \$53 million per year, when 40 percent of the population is covered, well under the cost of a strategic storage program. Even when the program is extended to the entire population, average program costs are low at \$142 million per year.

Even so, the average cost of the program masks rare events that may strain budgets and threaten the sustainability of the program. In our simulation, the maximum payouts, for a program-coverage of 40 percent of the population, was \$3,784 million—nearly 70 times average costs. At the same time, the value was an extreme one and 99 percent of the payouts were under \$1,338 million (about 25 times average cost).

The policy is designed to allow vulnerable households to consume at levels consistent with lower prices when wheat prices are high. For some households, the benefits are large and lasting, since the capacity to purchase more food precludes the long term consequences of even temporary periods of poverty and malnutrition. But it also means that, for the portion of the population covered, price does not ration demand. Specifically, when the market price reaches the ceiling price, protected consumers face a constant price and their demand becomes perfectly inelastic to prices. As a consequence, the program creates an added cost for most consumers, since less adjustment in demand leads to greater price volatility, both in MENA and in the rest of the world.

Quantitatively, simulations suggest that the average effect of the policy on volatility is small; extending the policy to all households in MENA would increase price volatility by about 1.2 percentage points.

Conclusions

In this paper, we describe a rational expectations model of competitive storage and trade, based on wheat markets for the Middle East and North Africa and the rest of the world. We use the model to quantify the

²⁴ In addition, local storage also protects domestic consumers from physical disruptions in trade. This is a real and practical source of risk for some countries, although it is not directly accounted for in our analysis.

effects of a strategic inventory policy designed to protect consumers in the region from very high prices. We find that, with a modest protection goal, the program can effectively protect consumers in MENA against steep price spikes, and by doing so lowers price volatility in the region. Moreover, because MENA is a large importer, releasing stocks when international prices are high lowers international prices since the released stocks displace MENA imports.

Theory and practical experience suggest that strategic reserve programs fail when a series of rare but eventual adverse events occur. The model suggests the probability of the program's failure can be reduced by holding greater reserves. A more aggressive restocking of spent reserves reduces failure risk as well, but the strategy can be destabilizing since larger purchases are made when international supplies are tight.

Making the strategic reserve program robust to failure drives up the program's costs. Simulations show that a targeted consumer subsidy program that insulates the most vulnerable from the upper range of price increases is a much less expensive alternative on average. Even so, the targeted program remains reliant on trade and adds slightly to global price volatility. In addition, the program is subject to rare peak expenditures that could undermine the policy when alternative risk-sharing financial instruments are unavailable.

References

- Ahmed, Shaikh S. 2005. Delivery Mechanisms of Cash Transfer Programs to the Poor in Bangladesh. Social Protection Discussion Paper 520. Washington: World Bank.
- Akiyama, Takamasa, John Baffes, Donald F. Larson and Panos Varangis. 2001. Commodity Market Reforms: Lessons of Two Decades. Washington, World Bank.
- Alderman, Harold and Trina Haque. 2006. Countercyclical safety nets for the poor and vulnerable. *Food Policy* 31(4), 372-383.
- Anderson, Jock, Charles Blitzer, Tom Cauchois, and Enzo Grilli, 1981. A dynamic simulation model of the world jute economy, *European Economic Review* 16(2), 303-331.
- Bardsley, Peter. 1994. The collapse of the Australian Wool Reserve Price Scheme. *The Economic Journal* 104 (426), 1087-1105.
- Bauer, P. T. and F. W. Paish. 1952. The reduction of fluctuations in the incomes of primary producers. *The Economic Journal* 62(248), 750-780.
- Brennan, Donna. 2003. Price dynamics in the Bangladesh rice market: implications for public intervention. *Agricultural Economics* 29(1), 15-25.
- Byerlee, Derek, Jayne T.S., and Robert J. Myers. 2006. Managing food price risks and instability in a liberalizing market environment: overview and policy options. *Food Policy* 31(4), 275-287.
- Cafiero, Carlo, Bobenrieth, E. S. A.; Bobenrieth, J. R. A. and Brian D. Wright. 2011. The empirical relevance of the competitive storage model. *Journal of Econometrics* 162(1), 44-54.
- Coleman, Andrew. 2009. Storage, slow transport, and the law of one price: theory with evidence from nineteenth-century U.S. corn markets. *Review of Economics and Statistics* 91(2), 332-350.
- Considine, Timothy and Donald F. Larson. 2001. Risk premiums on inventory assets: the case of crude oil and natural gas. *Journal of Futures Markets* 21(2), 109-126.
- Cunha Jesse M., Giacomo De Giorgi, Seema Jayachandran. 2011. The Price Effects of Cash Versus In-Kind Transfers. NBER Working Paper 17456. National Bureau of Economic Research. Cambridge, Mass.
- Deaton, Angus and G. Laroque. 1992. On the behaviour of commodity prices. *Review of Economic Studies* 59(1), 1-23.
- del Ninno, Carlo, Paul A. Dorosh, Kalanidhi Subbarao. 2007. Food aid, domestic policy and food security: Contrasting experiences from South Asia and sub-Saharan Africa, *Food Policy* 32(4), 413-435.
- Dercon, Stefan. 2005. Insurance against Poverty. Oxford: Oxford University Press.
- Dorosh, Paul A. 2008. Food price stabilization and food security: International experience. *Bulletin of Indonesian Economic Studies* 44(1), 93-114
- Fan, Ying, and Xiao-Bing Zhang. 2010. Modeling the strategic petroleum reserves of China and India by a stochastic dynamic game. *Journal of Policy Modeling* 32(4), 505-519.
- FAO. 2011. FAOSTAT database. Rome: Food And Agriculture Organization of the United Nations.

- Gardner, Bruce L. 1979. *Optimal Stockpiling of Grain*. Lexington, Massachusetts: Lexington Books.
- Gilbert, Christopher. 1996. International commodity agreements: an obituary notice. *World Development* 24(1), 1-19.
- Gouel, Christophe and Sébastien Jean. 2012. Optimal food price stabilization in a small open developing country, World Bank Policy Research Working Paper 5943. Washington: World Bank.
- Gustafson Robert L. 1958. Implications of recent research on optimal storage rules. *Journal of Farm Economics* 40(2), 290-300.
- Hall, Ben. "France's Sarkozy Unveils G20 Leadership Agenda." *Financial Times* 26/Aug/2010.
- Hayek, Frederich A. 1943. A commodity reserve currency (in post-war problems). *Economic Journal* 53(2), 176-184.
- Keynes, John M. 1938. The policy of government storage of foodstuffs and raw materials. *Economic Journal* 48(191), 449-460.
- Knudsen, Odin and John Nash. 1990. Domestic price stabilization schemes in developing countries. *Economic Development and Cultural Change* 38(3), 539-58.
- Lampietti, Julian, Sean Michaels, Nicholas Magnan, Alex McCalla, Maurice Saade, Nadim Khouri. 2011. A strategic framework for improving food security in Arab countries. *Food Security* 3(Suppl), S7-S22.
- Larson, Donald F. 2007. On inverse carrying charges and spatial arbitrage. *Journal of Futures Markets* 27(4), 305-336.
- Larson, Donald F. and Jonathan Coleman. 1993. The effects of option hedging on the costs of domestic price stabilization schemes. In S. Claessens and R. Duncan (eds.) *Commodity Risk Management and Finance*, Volume 2. Oxford University Press, Oxford.
- Larson, Donald F., Jock R. Anderson and Panos Varangis. 2004. Policies on managing risk in agricultural markets, *World Bank Research Observer* 19(2), 199-230.
- Mahul, Olivier and Ghesquiere, Francis, 2007. *Sovereign Natural Disaster Insurance for Developing Countries: A Paradigm Shift in Catastrophe Risk Financing*. World Bank Policy Research Working Paper 4345. Washington: World Bank.
- Makki, Shiva S., Luther G. Tweeten and Mario J. Miranda. 1996. Wheat storage and trade in an efficient global market. *American Journal of Agricultural Economics* 78(4), 879-890.
- Massell, Benton F. 1969. Price stabilization and welfare. *Quarterly Journal of Economics* 83(2), 234-289.
- Massell, Benton F. 1970. Some welfare implications of international price stabilization. *The Journal of Political Economy* 78(2), 404-417.
- Miranda, Mario J. and Joseph W. Glauber. 1995. Solving stochastic models of competitive storage and trade by Chebychev Collocation methods. *Agricultural and Resource Economics Review* 24(1), 70-77.
- Myers, Robert J. and Oehmke, J.F. 1988. Instability and risk as rationales for farm programs. In D.A. Sumner (ed.), *Agricultural Stability and Farm Programs: Concepts, Evidence, and Implications*, Westview, Boulder, 1-22.

- Mykerezi, Elton, and Bradford Mills. 2010. The impact of food stamp program participation on household food insecurity . *American Journal of Agricultural Economics* 92(5), 1379-91.
- Newbery, David, and Joseph Stiglitz. 1981. *The theory of Commodity Price Stabilization*. Oxford: Clarendon Press.
- Peters, May, Suchada Langley and Paul Westcott, "Agriculture Commodity Price Spikes in the 1970's and 1990's: Valuable Lessons for Today." *Amber Waves*, March 2009.
- Roberts, Michael J. and Wolfram Schlenker. 2009. World supply and demand of food commodity calories. *American Journal of Agricultural Economics* 91(5), 1235-1242.
- Sabates-Wheeler, Rachel and Stephen Devereux. 2010. Cash transfers and high food prices: Explaining outcomes on Ethiopia's Productive Safety Net Programme. *Food Policy* 35(4), 274-285.
- Salant, Stephen W. 1983. The vulnerability of price stabilization schemes to speculative attack. *The Journal of Political Economy* 91(1), 1-38.
- Skees, Jerry, Panayotis N. Varangis, Donald F. Larson and Paul Siegel. 2005. Can financial markets be tapped to help poor people cope with weather risks? In *Insurance against Poverty*, S. Dercon (ed.), New York, Oxford University Press.
- Srinivasan, P. V. and Shikha Jha. 2001. Liberalized trade and domestic price stability. The case of rice and wheat in India. *Journal of Development Economics* 65(2), 417-441.
- Thomas, Anisya and Lynn Fritz. 2006. Disaster Relief, Inc. *Harvard Business Review* 84 (11), 114-122.
- USDA. 2011. United States Department of Agriculture, Foreign Agricultural Service, Production, Supply, and Distribution Database and USDA, World Agricultural Outlook Board, World Agricultural Supply and Demand Estimates. Available on the Internet at <http://www.ers.usda.gov/Data>.
- Van Wassenhove, L.N. 2006. Humanitarian aid logistics: supply chain management in high gear. *Journal of the Operational Research Society*. 57, 475-489.
- Victor, David G., and Sarah Eskreis-Winkler. 2008. In the tank: making the most of strategic oil reserves. *Foreign Affairs* 87(4), 70-83.
- von Braun, Joachim and Maximo Torero. 2009. Implementing Physical and Virtual Food Reserves to Protect the Poor and Prevent Market Failure. IFPRI Policy Brief 20 (February, 2009). Washington: International Food Policy Research Institute.
- Williams, Jeffrey C. and Brian D. Wright. 1991. *Storage and Commodity Markets*. Cambridge: Cambridge University Press.
- Working, Holbrook. 1948. Theory of the inverse carrying charge in futures markets. *Journal of Farm Economics* 30(1), 1-28.
- World Bank. 2007. *Making the Most of Scarcity: Accountability for Better Water Management in the Middle East and North Africa*. MENA Development Report. The World Bank.
- World Bank. 2009. *Improving Food Security in Arab Countries*. Washington: World Bank.

- World Bank. 2011a. Food Price Hike Drives 44 Million People into Poverty. Press Release No: 2011/333/PREM. Washington: World Bank.
- World Bank, 2011b. Global Economic Prospects (June 2011). Washington: World Bank.
- World Bank, 2011c. Facing Challenges and Opportunities. World Bank Middle East and North Africa Region – A Regional Economic Update, May 2011. World Bank.
- World Bank and the Food and Agriculture Organization of the United Nations. 2012. The Grain Chain: Food Security and Managing Wheat Imports in Arab Countries. Washington, DC. World Bank.
- Wright, Brian D. 1979. The effects of ideal production stabilization: a welfare analysis under rational expectations. *Journal of Political Economy* 87(5), 1011-33.
- Wright, Brian D. 2001. Storage and price stabilization, in Bruce L. Gardner and Gordon C. Rausser, ed., *Marketing, Distribution and Consumers*, Elsevier, Amsterdam, pp. 817-861.
- Wright, Brian D. and Carlo Cafiero. 2011. Grain reserves and food security in the Middle East and North Africa. *Food Security* 3(Supplement 1), 61-76.
- Wright, Brian D. and Jeffrey C. Williams. 1982. The economic role of commodity storage. *The Economic Journal* 92(367), 596-614.
- Wright, Brian D. and Jeffrey C. Williams. 1984. The welfare effect of introduction of storage. *The Quarterly Journal of Economics* 99(1), 169-82.
- Wright, Brian D. and Jeffrey C. Williams. 1988. The incidence of market-stabilising price support schemes. *Economic Journal* 98(393), 1183-98.
- Yamey, Basil. 1992. The Tin Crisis (1985-86) and futures trading. *Economic Record* 68 (supplement), 10-15.
- Zoellick, Robert. Free markets can still feed the world. *Financial Times* 05/Jan/2011.

Table 1: Selected wheat statistics, average 2005-07

	Net trade (Imports- Exports) (thousand ton)	Domestic consumption (thousand ton)	Trade share of domestic consumption (%)	Share of total calories from wheat (%)
Algeria	5,405	7,883	69	46
Bahrain	27	27	100	—
Egypt	7,569	15,267	50	35
Iran	510	15,200	3	43
Iraq	3,772	6,209	61	—
Jordan	848	830	102	38
Kuwait	294	294	100	23
Lebanon	313	450	69	30
Libya	1,430	1,455	98	40
Morocco	2,673	7,075	38	41
Oman	147	147	100	—
Saudi Arabia	85	2,500	3	27
Syria	-556	4,306	-13	39
Tunisia	1,596	2,933	54	48
United Arab Emirates	514	514	100	29
Yemen	2,166	2,311	94	38
MENA	26,793	67,404	40	—
Rest of the World	-26,793	548,788	-5	—

Notes: Estimates of the share of daily calories derived from wheat are taken from FAO (2011). The remaining data is from USDA (2011).

Table 2: Model calibration values

		MENA	RoW
Calibration target at steady state			
Consumption (million ton)		75.3	592.9
Production (million ton)		40.2	628
Price (\$/ton)		211.55	176
Demand elasticity			-0.12
Supply elasticity			0.2
Parameter	Economic interpretation		
a^i	Intercept of demand curve	84.336	664.048
b^i	Slope of demand curve	0.043	0.404
c^i	Intercept of marginal cost function	-805.905	-670.476
d^i	Slope of marginal cost function	25.059	1.335
$\text{std}(\varepsilon^i)$	Standard deviation of production shocks	0.07	0.03
r	Interest rate (%)		5
k	Physical storage cost (\$/ton)		22.4
θ	Trade cost (\$/ton)		35.55

Notes: Consumption, production and price in RoW targets are determined as the trend values in 2011 after applying an Holdrick-Prescott filter (smoothing parameter of 400) on the underlying data (USDA, 2011, for consumption and production and World Bank, 2011b, for the price). RoW consumption is adjusted to ensure global market equilibrium. MENA price target is defined by adding transport cost to RoW price.

Table 3: Coefficient of variation of main variables (percentage)

	Simulated		Observed	
	MENA	RoW	MENA	RoW
Price	16.36	19.63	—	17.85
Exports	—	8.58	—	10.61
Demand	1.98	2.38	1.16	1.68
Production	7.01	3.04	7.54	3.46

Notes: Simulated statistics are calculated over 100,000 sample observations from the asymptotic distribution. Observed values are determined from applying a Holdrick-Prescott filter (smoothing parameter of 400) on the underlying data (USDA, 2011, for consumption, production and exports and World Bank, 2011b, for the price).

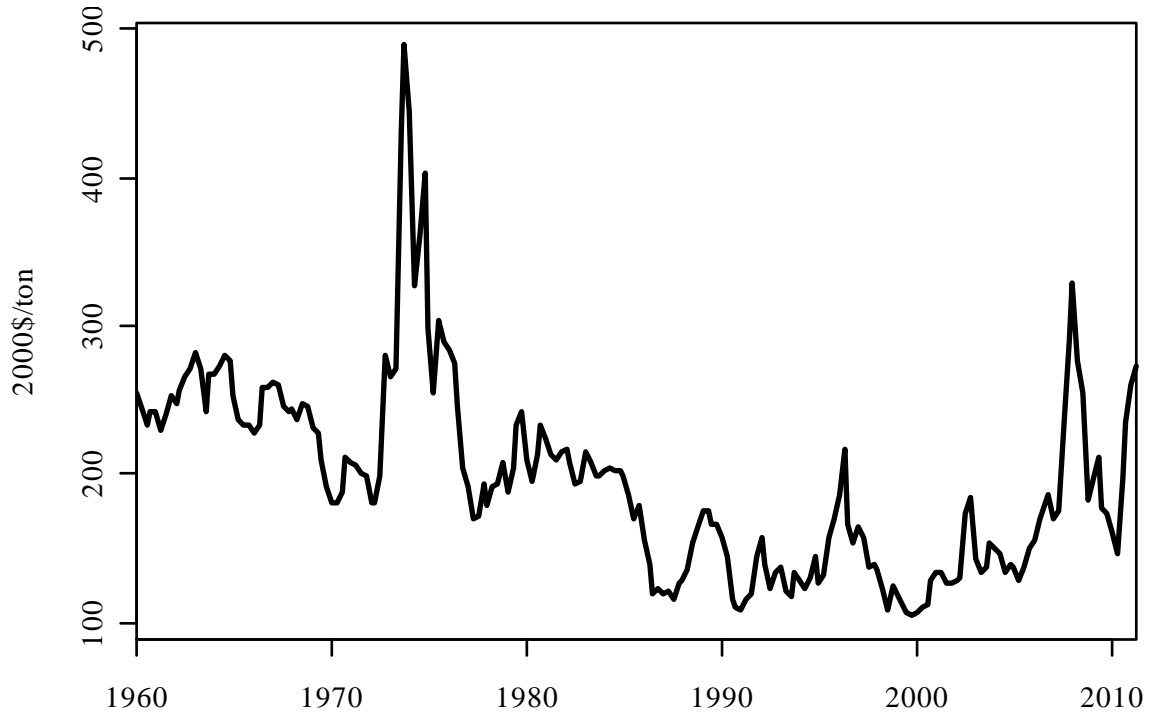


Figure 1: Real quarterly wheat prices. Wheat (US), no. 1, hard red winter, ordinary protein, export price delivered at the US Gulf port for prompt or 30 days shipment. *Source:* World Bank (2011b).

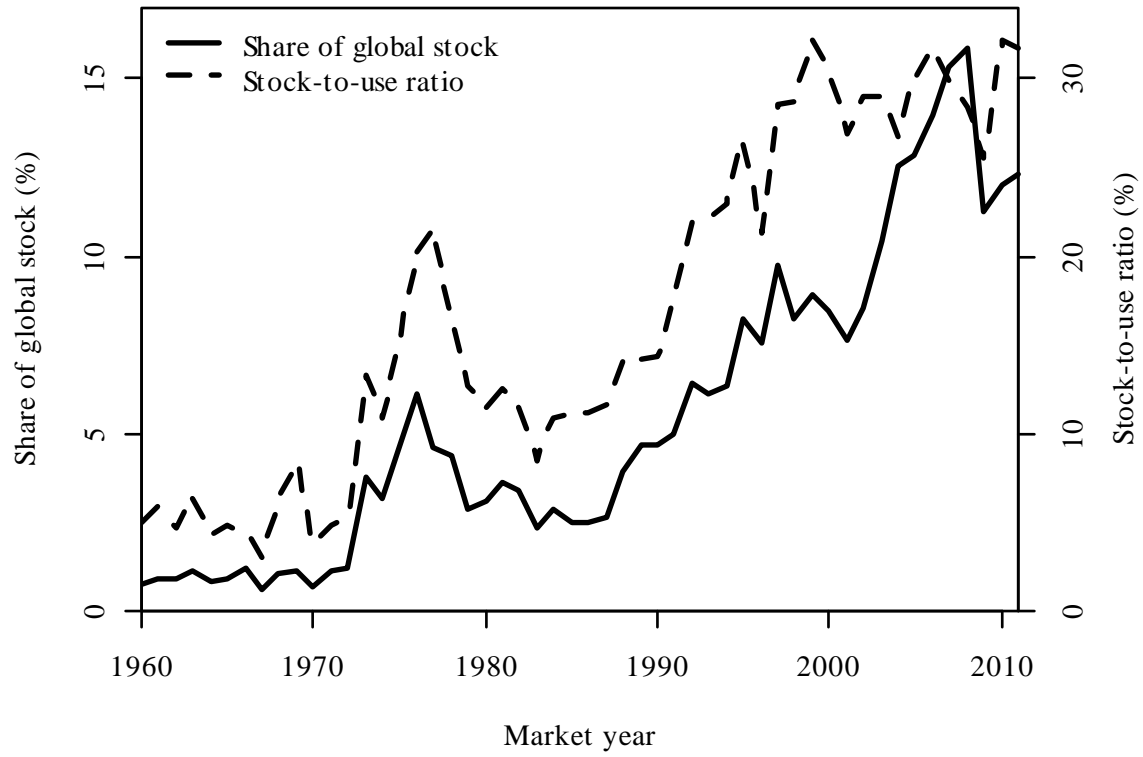


Figure 2: Share of global wheat stocks and stock-to-use ratio in the MENA region. *Source: USDA (2011).*

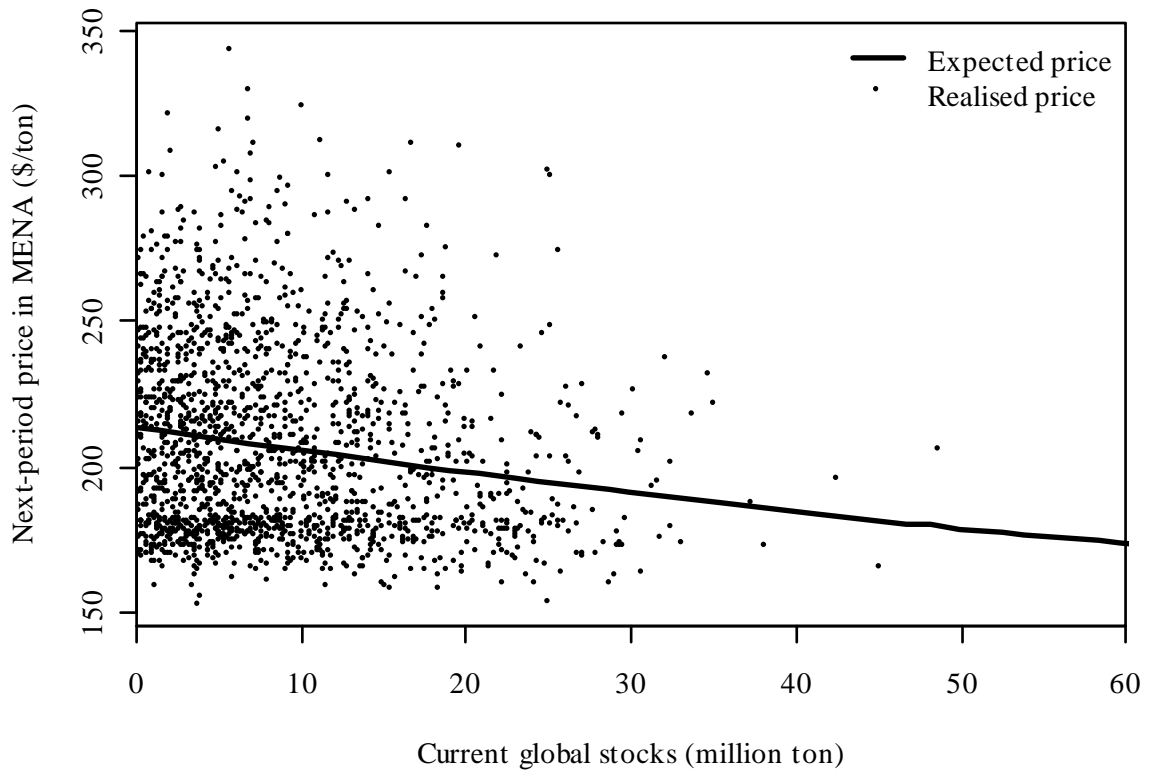


Figure 3: Starting inventories and next period price from benchmark-model simulations

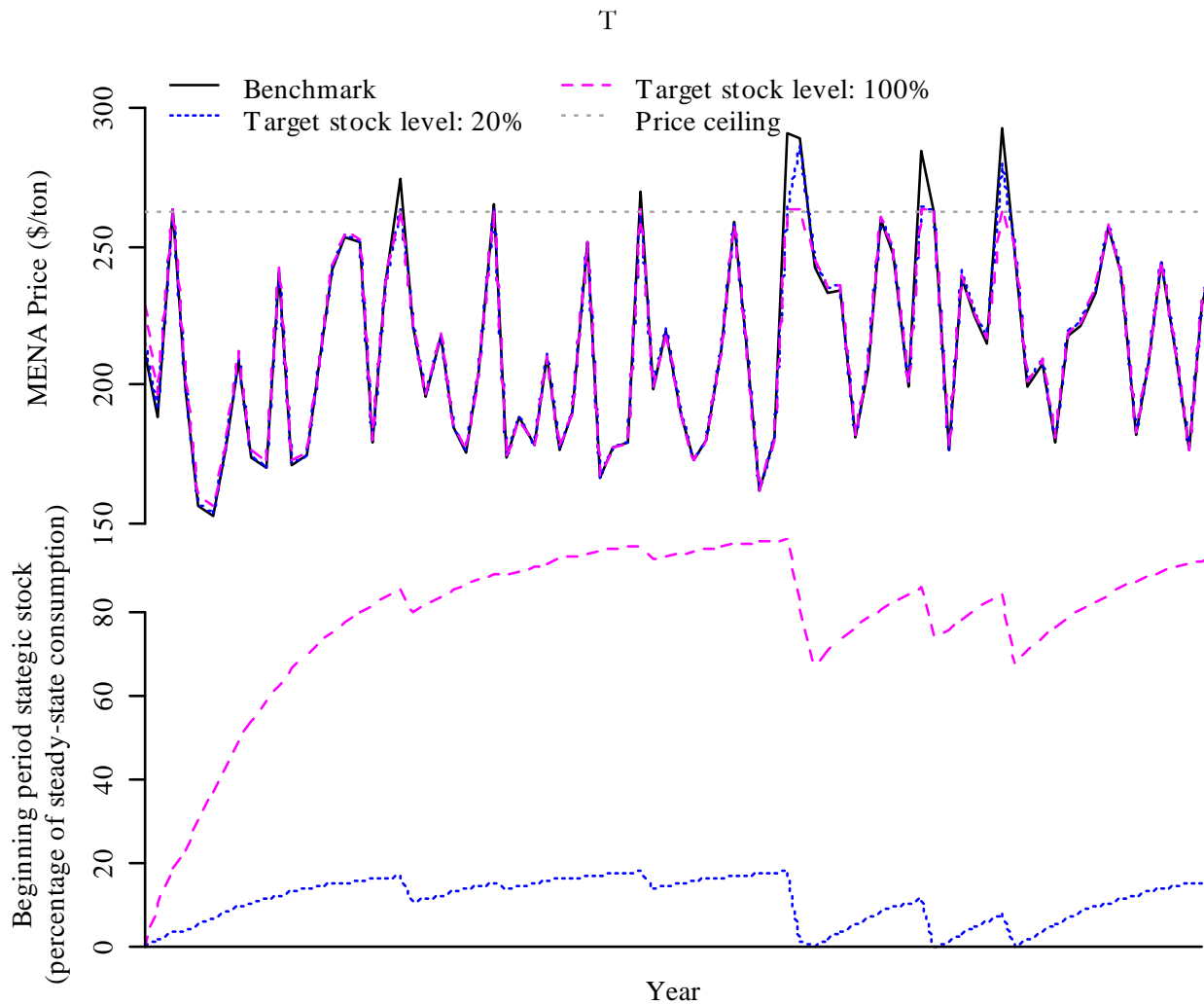


Figure 4: Sample simulation of price and strategic stock level in MENA. The simulations start from the non-stochastic steady state, correspond to the same production shocks and are generated under the assumption of a 10 percent build-up rate.

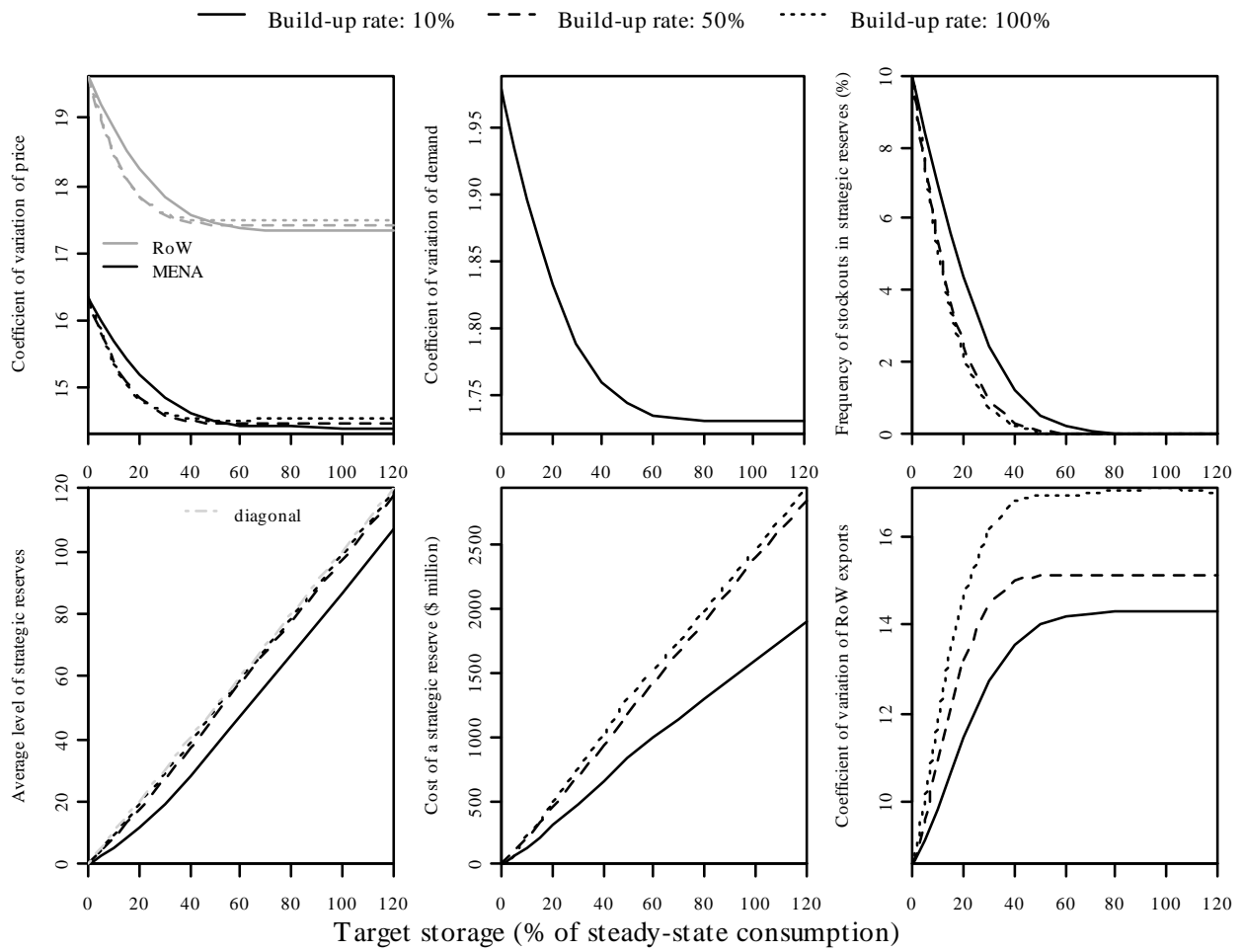


Figure 5: Effects of a strategic reserve policy for various levels of target storage. Statistics calculated over 100,000 sample observations from the asymptotic distribution.

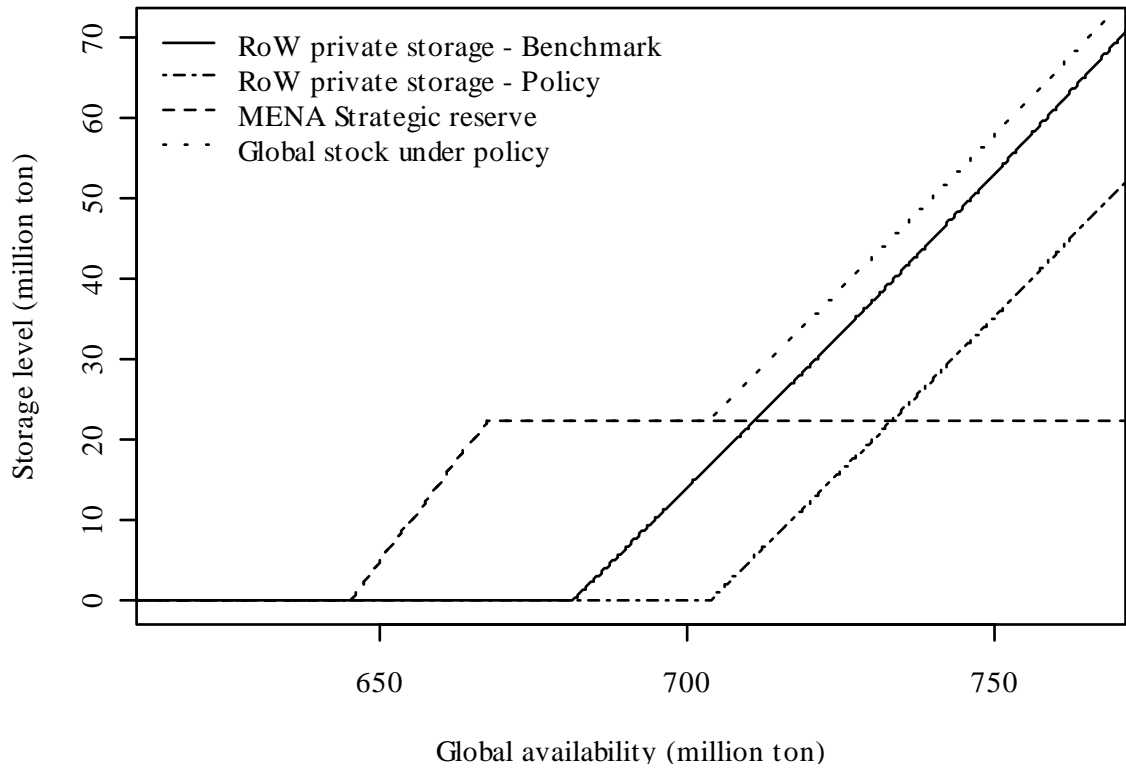


Figure 6: Storage rules for the benchmark and for one strategic reserve policy ($\alpha = 1, \bar{S}^G = 22.6$)

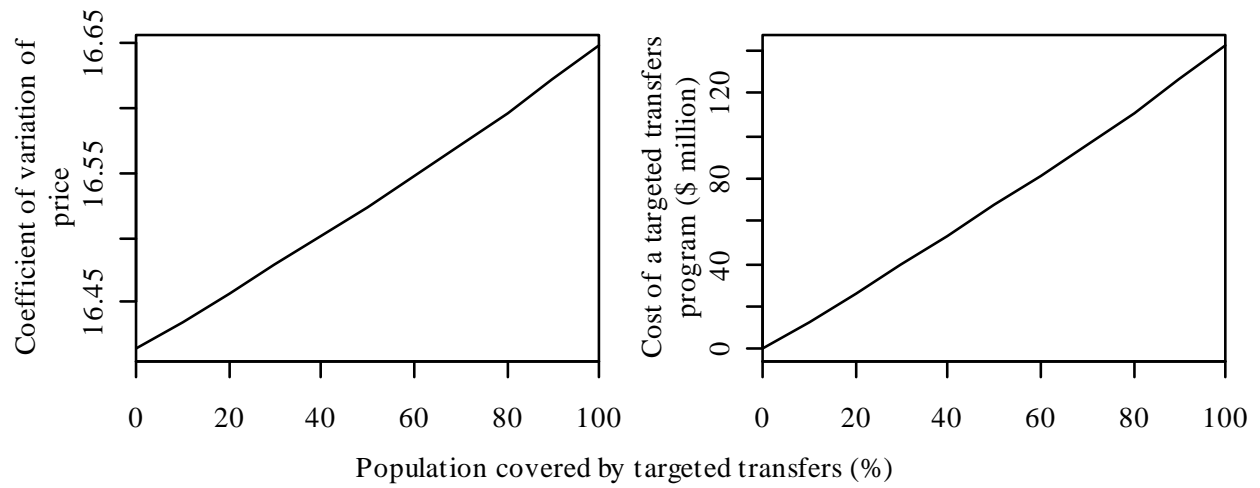


Figure 7: Effects of a program of targeted transfers. Statistics calculated over 100,000 sample observations from the asymptotic distribution.

Annex Table 1

Storage target	MENA CV of price			RoW CV of price			MENA CV of demand			Prices exceed target		
	Buildup rate			Buildup rate			Buildup rate			Buildup rate		
	0.1	0.5	1	0.1	0.5	1	0.1	0.5	1	0.1	0.5	1
0.00	16.359	16.359	16.359	19.634	19.634	19.634	1.979	1.979	1.979	10.000	10.000	10.000
0.01	16.284	16.236	16.246	19.546	19.487	19.497	1.970	1.964	1.966	9.678	9.438	9.465
0.05	16.004	15.810	15.843	19.211	18.979	19.008	1.935	1.911	1.921	8.415	7.478	7.533
0.10	15.698	15.393	15.348	18.845	18.481	18.428	1.897	1.860	1.853	6.974	5.426	5.106
0.15	15.424	15.068	15.058	18.518	18.095	18.080	1.863	1.818	1.818	5.628	3.703	3.429
0.20	15.188	14.847	14.827	18.238	17.833	17.813	1.833	1.789	1.784	4.386	2.447	2.132
0.30	14.842	14.605	14.621	17.826	17.548	17.570	1.788	1.756	1.757	2.435	0.925	0.733
0.40	14.629	14.505	14.546	17.576	17.436	17.487	1.760	1.742	1.746	1.266	0.288	0.197
0.50	14.507	14.467	14.524	17.437	17.400	17.469	1.743	1.736	1.743	0.546	0.056	0.018
0.60	14.450	14.461	14.528	17.375	17.395	17.474	1.736	1.735	1.744	0.208	0.009	0.002
0.70	14.428	14.461	14.534	17.351	17.394	17.479	1.732	1.735	1.746	0.077	0.002	0.001
0.80	14.419	14.460	14.539	17.342	17.394	17.484	1.731	1.735	1.747	0.030	0.000	0.000
1.00	14.415	14.460	14.543	17.337	17.394	17.488	1.731	1.735	1.748	0.000	0.000	0.000
1.20	14.414	14.461	14.531	17.335	17.394	17.476	1.731	1.735	1.745	0.000	0.000	0.000

Note: The last three columns are the percentage of simulated observations when MENA domestic prices exceed the target price. CVs are expressed as percentages.

Annex Table 2

Storage target	Strategic reserves (million tons)			Cost of reserves (\$US million)			RoW CV of exports (percentage)		
	0.1	0.5	1	0.1	0.5	1	0.1	0.5	1
0.00	0.00	0.00	0.00	0	0	0	8.58	8.58	8.58
0.01	0.36	0.62	0.68	15	22	20	8.66	8.73	8.76
0.05	1.89	3.16	3.43	74	104	69	9.12	9.61	9.98
0.10	3.99	6.47	6.96	139	209	228	9.85	10.95	11.77
0.15	6.32	9.91	10.55	218	331	330	10.67	12.20	13.48
0.20	8.89	13.46	14.23	303	451	492	11.45	13.21	14.66
0.30	14.73	20.78	21.66	478	692	753	12.75	14.47	16.17
0.40	21.32	28.25	29.16	655	929	1,016	13.57	14.98	16.76
0.50	28.38	35.78	36.69	827	1,172	1,297	14.00	15.08	16.88
0.60	35.69	43.31	44.21	986	1,410	1,520	14.19	15.10	16.93
0.70	43.11	50.84	51.74	1,138	1,649	1,741	14.26	15.11	16.98
0.80	50.56	58.37	59.26	1,289	1,892	1,974	14.29	15.11	17.03
1.00	65.49	73.43	74.32	1,593	2,389	2,465	14.31	15.11	17.06
1.20	80.43	88.49	89.39	1,899	2,838	2,934	14.31	15.11	16.97