Managing Food Price Volatility in a Large Open Country

The Case of Wheat in India

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Disclaimer:

Acronyms and Abbreviations

AAY	Antyodaya Anna Yojana
APL	Above the poverty line
BPL	Below the poverty line
cif	Cost, insurance, freight
CV	Coefficient of variation
FAO	Food and Agriculture Organization of the United Nations
fob	Free on board
MSP	Minimum Support Price
PDS	Public Distribution System
RoW	Rest of the world
Rs	Indian rupee
t	Ton
US	United States
US$	United States dollar

Executive Summary

India has pursued an active food security policy for many years using a combination of trade policy interventions, public distribution of food staples, and assistance to farmers through minimum support prices defended by public stocks. This policy has been quite successful in stabilizing staple food prices, but stabilization has come at a high cost raising concerns whether the costs exceed the associated benefits. Further, it carries the risk of accumulating unmanageably large stocks, even as food prices remain high, as has been the case in recent years with stocks far exceeding the established norms for buffer stocks and strategic reserves.

To analyze the welfare and cost implications of the current policies, this study relies on a rational expectations storage-trade model to represent India's wheat market and its relations with the rest of the world. The model helps evaluate the current policies for managing wheat price volatility in India and consider alternative stabilization policies. Representing current policies is a challenge, however, because they appear to be highly discretionary. To capture their essence, they have been represented as simple rules, defined as functions of world and domestic conditions. The alternative stabilization policies are derived from the maximization of a social welfare function that includes a motivation for price stability. The model developed in this study contains two innovations for developing price stabilization policies: It designs optimal price stabilization policies for a large-country case, and it considers simple rules for stabilization and demonstrates how closely their effects can approximate those of a fully optimal policy.

The current policies pursued by India are costly for two reasons: trade and storage policies are not well coordinated, and in the absence of clearly defined rules for the release of stocks (other than for PDS), the storage policy effectively translates to a buy-and-hold strategy. Large stock levels are held for long periods, and procurement continues regardless of the current level of stocks. But stock releases, beyond the PDS releases, are insufficient to dampen domestic price rises or keep stock levels in check. Instead, the government has occasionally had to dispose of wheat stocks on the world market.

Another key food policy issue for India is the cost of public grain storage. The current costs, declared by the Food Corporation of India, are four times higher than long-run costs estimated for other countries by the World Bank and Food and Agriculture Organization (FAO) (2012). Such high costs make it extremely difficult to justify public storage in India on economic grounds, as it would be much less costly to rely on domestic private storage or on world trade and storage abroad. For that reason, the alternative policies considered here are based on providing sufficient incentives to induce more cost-efficient private stock holders, or a lower-cost public storage agency, to store grains in a socially optimal way.

The model is used to identify the levels of storage and trade under an optimal policy maximizing total welfare. But since a fully optimal policy is state-dependent and may be difficult to implement, more practical policy guidance may be obtained using some optimal simple rules for stabilization. These are simple pre-determined rules of public policy whose parameters are chosen to maximize the same the same welfare function. Two simple rules considered are a constant subsidy to private storage (as storage policy) and tariffs defined by an isoelastic function of border price (as trade policy). A notable result from the model is that the optimal simple rules achieve welfare gains approaching those obtained by implementing a fully optimal policy. Under simple policy rules, private storage is incentivized to exceed a storage level above the competitive level. Since private storage reacts in appropriate ways to price behavior, it combines well with the trade policy, a result that is extremely difficult to achieve with a price-band program (or its variants).

Two main messages emerge from the analysis in this paper. One is that the broad approach adopted by India, using a combination of trade and storage policies, is appropriate. The second is that, using this combination of policies with some modifications, India could significantly improve its total welfare and reduce its costs (primarily storage costs). Price stabilization policies are generally not regarded as first-best policies as they do not directly target the underlying market failures, which are often thought to be related to the economic agents' lack of capacity to cope with shocks. Yet price stabilization policies hold considerable appeal for many policy makers given their strong dislike for price instability and the fact that certain market failures may prevent the first-best policy options from achieving their goals. Considering these factors, it is important to identify better policies to achieve price stability.

In India, given the current circumstances, it appears that significant cost savings (through a combination of storage and trade costs) could be made without any significant net loss in pure welfare (defined as the sum of producers or consumers surplus) through a less insulating trade policy implemented in conjunction with storage rules that are similar to, but above, competitive storage levels. These gains are predicated on efficient storage, however. The current public costs of storage are extremely high and make it difficult to justify any level of public storage in the country without significant overall loss in welfare.

Managing Wheat Price Volatility:
Evaluating Policy Options

1   Introduction

India has aggressively pursued food security for many years. For India's policy makers, the prices of staple foods—particularly wheat and rice—raise major concerns. To protect poor consumers from high prices, and to lower the cost of food in normal times, a Public Distribution System (PDS) provides food to low-income consumers at concessional prices. To protect producers from low prices, a pre-announced Minimum Support Price (MSP) places an effective floor on domestic prices, defended by the government's accumulation of staple food stocks. India also pursues an active trade policy to insulate the domestic market from fluctuations in world prices of these staples. Together, these policies have stabilized domestic prices, but concern is growing over the policies' mounting costs, potential inefficiencies, and the stark juxtaposition of large and growing public stocks with rising food prices (Basu 2011).

Concern about food prices is common in countries with many poor people who are vulnerable to price spikes or price slumps. In that context, policy makers often favor policies that reduce the volatility of staple food prices. Such policies have been especially prevalent since the 2007/08 world food crisis, which highlighted the potential instability in world food markets (Demeke, Pangrazio, and Maetz 2009; Gouel 2014).

This study looks at alternatives to address some of the challenges facing policy makers in these situations. Based on the assumption that policy makers seek to maximize social welfare, and specifically taking into account their dislike for price volatility, this study assesses current policies for wheat in India and then examines alternatives. The analysis relies on a rational expectations model of storage and trade that represents two regions—India and the rest of the world—and their interaction on the wheat market. The economic agents in the model include producers, consumers, and holders of stocks. Producers base their planting decisions on expected prices at harvest time. Stock holders make decisions on how much to store from one year to the next based on the price they expect next year, the price of grain this year, and the cost of storage. International trade is represented by spatial arbitrage conditions. Current policies are incorporated by identifying patterns that enable them to be represented as simple rules, defined as functions of world and domestic conditions. The model is calibrated using 2012 data on India's wheat market and solved numerically.

Alternative stabilization policies are designed based on the maximization of a social welfare function that includes a quadratic loss function in prices. In addition to a fully optimal policy, which gives welfare-maximizing levels of storage and trade in all situations, the use of simple rules of intervention is also considered. Past research suggests that simple rules might

yield a large share of the benefits of an optimal policy (Gouel 2013c) while being easier to design and to implement. The simple rules considered are a constant subsidy to private storage and trade tariffs defined by an isoelastic function of the border price.

A final issue addressed in the study is the cost of public storage in India, which appears to be much higher than in other countries. With such high costs, public storage is extremely difficult to justify on economic grounds. It would be far less costly to rely on domestic private storage or on world trade and storage abroad.

Beyond the analysis of current and alternative policies for wheat in India, this study contributes to the literature on the design of food price stabilization policies (Gouel 2013a, 2013c; Gouel and Jean 2014). It augments the modeling undertaken for previous studies by considering the case of a large country. Modeling a large-country case makes it possible to assess the effect of counter-cyclical policies on the world market, a very contentious issue since the 2007/08 spikes in food prices, which were partially precipitated by widespread use of export restrictions (Martin and Anderson 2012). A second contribution of this study is that it confirms, for an open-economy setting, Gouel's (2013c) results that optimal simple rules can achieve welfare gains close to those from fully optimal rules. Optimal simple rules are found to be slightly less successful in an open economy setting compared to a closed economy setting, however, because they do not exploit the country's market power as do fully optimal policies.

After the main features of India's wheat market are outlined in Section 2, Section 3 develops the model representing India's wheat market and its relation to the world market. A representation of welfare in this framework is proposed, taking into account the observed preference for food price stability (Section 4). A core assumption is that the cost of risk to policy makers rises more than proportionately with deviations from the mean price. Section 5 begins by considering the mathematical representation of current policies and the design of alternative stabilization policies. The objective function and the structure of the model make it possible to identify a set of optimal policies that minimize the costs of any given degree of volatility. Simple rules of intervention are considered as well. Section 6 develops a numerical calibration for the model and presents the numerical results. Section 7 presents the conclusions.

2 India's wheat market

India has undergone a major transformation since the 1960s, from being a highly insecure food importer to a consistent net-exporter of agricultural products (Gulati, Jain, and Hoda 2013), and from a policy framework that discriminated against agriculture to a relatively more neutral domestic policy regime (Pursell, Gulati, and Gupta 2009). The evolution of India's

wheat market reflects this profound transformation—from being a chronic food-aid recipient to an often substantial net-exporter (Figure 1, left panel).

Figure 1: Wheat trade and stock levels in India
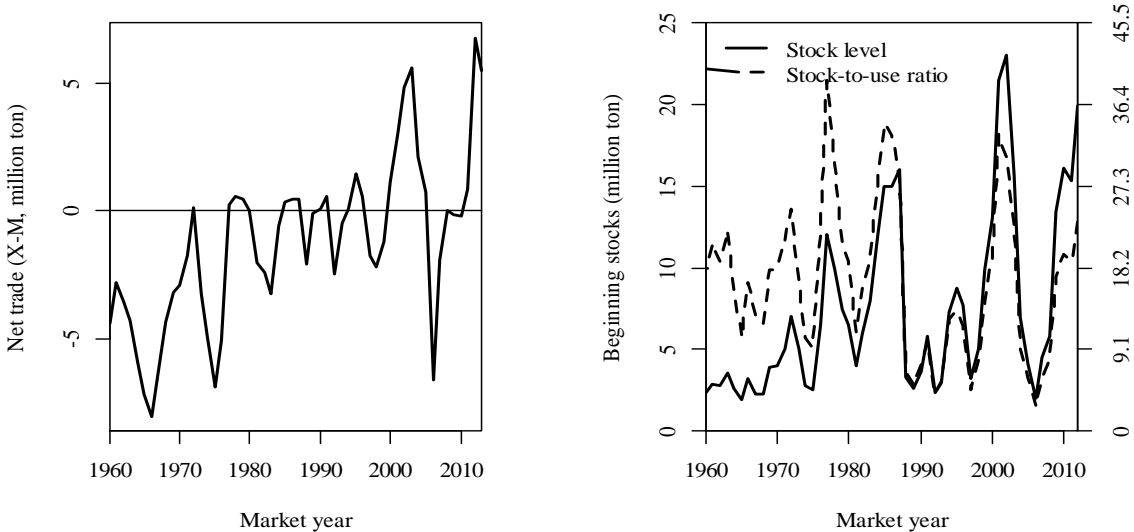
Source: USDA 2013.

Traditionally India has sought to achieve food security through actions to ensure that food is available and accessible. Policy has focused on an aggressive drive toward self-sufficiency in food grains, encompassing comprehensive support to farmers through the introduction of improved varieties and inputs; rapid expansion of irrigated area; subsidies of various inputs; efforts to maintain relatively stable producer prices; and management of the long-run relationship between domestic and world prices.

Protecting poor consumers through stable market prices and access to subsidized food has been another major feature of India's food policy. Aside from these interventions, for decades the government has maintained public stocks of food grains to buffer against production shocks, assist in maintaining national food self-sufficiency, stabilize food prices, and supply the PDS. These policies are supplemented with highly interventionist trade policies that rely on a combination of tariffs and periodic quantitative restrictions.

These policies have been highly successful in stabilizing both production and prices. Irrigation expansion in particular has been a major contributor to wheat production stability, with over 90 percent of wheat cultivated now on irrigated land (Figure 2). The reduction in production variability is even more impressive considering output now is almost four times the level in 1970.[4]

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[4] It is important to note that while production shocks, driven by the vagaries of the monsoons, are a fact of life in India, the largest production decline since 1950-51 was in 2002-03 at 7.01 million tons in absolute terms and 10% in relative terms from the production level of the previous year. In terms of rainfall, 1972 and 2009 had

Figure 2: Stability of Wheat production and irrigation expansion
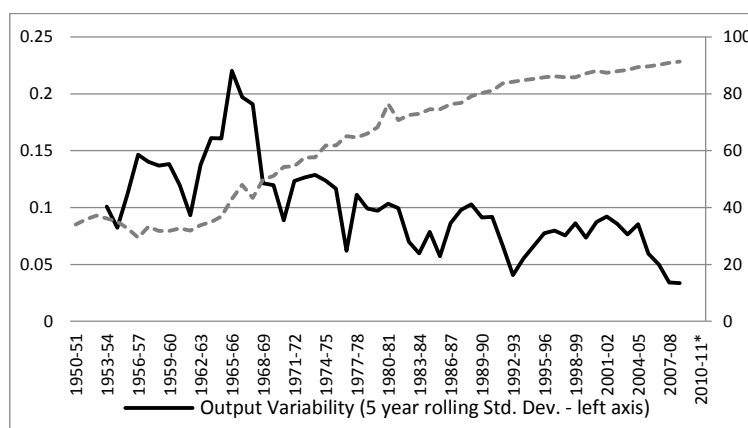
Source: Authors using data from Directorate of Economics and Statistics, Dept. of Agric. and Cooperation

With higher and more stable output, the government is compelled to procure increasing volumes of wheat at the pre-announced MSP. It acquires wheat early in the marketing season and then uses the accumulated stocks throughout the year to supply the PDS. Since the quantities procured at the minimum price may exceed the needs of the PDS, it is necessary at times to dispose of excess stocks. These releases are made on a discretionary basis, however, and as Basu (2011) explains, an emphasis on selling the stored grains at prices that cover the purchasing price and storage costs frequently makes it impossible to dispose of stocks in this way. Basu also notes that releases often fail to occur in periods of high prices. On occasion, the excessive accumulation of stocks requires the government to export its stocks, including by writing down the price, as reportedly done in 2002–03 (Ganesh-Kumar et al. 2012).

From 2007, during several years of high world prices, India used trade barriers to restrict grain exports and keep domestic prices down. The net outcome of these actions, together with public procurement, has been a substantial rise in stocks (Figure 1, right panel). The trade policy measures pushed domestic prices down relative to world prices, making the MSP the effective market price and requiring increases in stocks to support this price. Trade and stockholding policies appear to have been working against each other during this period, with trade policies holding down domestic prices while stock accumulation in support of the MSP drove them up.

3   Core model: The laissez-faire situation

A rational expectations two-country storage-trade model (similar to Larson et al. 2014 and following the first development of a storage trade model by Williams and Wright 1991, Ch. 9) is used to model the market for wheat in the absence of any intervention—a context in which

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the worst monsoon years over the past 110 years, each experiencing 22% less rainfall than the 110 year average. Yet wheat production fell in 1972 by only 1.7% but grew marginally (0.02% or 0.1 million tons) in 2009.

behavior does not follow from government decisions but from the economic responses of decentralized firms and consumers. It is a partial equilibrium model, representing the behavior in each country of competing stock holders, producers, and consumers. This model is a departure from previous studies on India (such as Srinivasan and Jha 2001) in that it represents the rest of the world (RoW) not as an exogenous price process but as a single large "country" with its own demand and stochastic supply. This specification is important for two reasons. First, a storage model is a better representation of world price dynamics than any simple dynamic process (Cafiero et al. 2011). Second, although the policy response of the RoW is not modeled, important feedback effects between India's food policy and the behavior of the RoW take place through the reactions of private stock holders and producers in India and abroad. These effects can be accounted for only if all agents are explicitly represented. With respect to the RoW, India represents a large share of the market, so India's stabilization policies affect the world market.

Regions RoW and India are indicated by the subscript $r \in \{w, i\}$. Producers make their production choices and pay for inputs one period before bringing output to market. However, actual production is uncertain. The difference between planned and actual production is a random shock, which is the source of volatility that drives price volatility in the model. The production decision is based on maximization of expected profit given by:

$$\Pi_{t|t+1}^r = \delta E_t(P_{t+1}^r \overline{H}_t^r \epsilon_{t+1}^r) - \Psi^r(\overline{H}_t^r), \tag{1}$$

where $\Psi^r(\overline{H}_t^r)$ is the cost of planned production level $\overline{H}_t^r$, which is affected in $t + 1$ by the multiplicative random disturbance ϵ_{t+1}^r; δ is the discount factor; and E_t is the mathematical expectations operator conditional on information available at time t. Profit maximization by producers gives the following intertemporal equation:

$$\delta E_t(P_{t+1}^r \epsilon_{t+1}^r) = \Psi^{r\prime}(\overline{H}_t^r). \tag{2}$$

Competitive stock holders' behavior is defined by the following condition:[5]

$$S_t^r \geq 0 \perp P_t^r + k^r - \delta E_t P_{t+1}^r \geq 0, \tag{3}$$

where S^r denotes private stock levels and k^r storage costs. The implication is that storage occurs when the returns to storage, net of the time value of money and physical storage costs, are expected to be positive. Competitive storage takes place when the returns to holding stocks are expected to equal or exceed the cost of holding stocks.

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[5] 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 a strict inequality, the remaining side holds as a strict equality.

Unless policies otherwise intervene, trade takes place between the two markets, and the world price is endogenously determined. Differences between production, consumption, and storage in the two regions are balanced by trade. Trade is decided by the spatial arbitrage condition:

$$X_t^r \geq 0 \perp P_t^r + \theta_{r,s} \geq P_t^s \text{ for } s \neq r, \tag{4}$$

where X^r denotes the exports from r and $\theta_{r,s}$ the transport cost from r to s.

The model has two state variables: the availability in both countries, A_t^r, defined as the sum of production and private carry-over:

$$A_t^r \equiv S_{t-1}^r + \bar{H}_{t-1}^r \varepsilon_t^r. \tag{5}$$

Market equilibrium can be written as:

$$A_t^r + X_t^s = D^r(P_t^r) + S_t^r + X_t^r \text{ for } s \neq r. \tag{6}$$

The demand function is assumed to be isoelastic: $D^r(P_t^r) \equiv d^r P_t^{r\alpha^r}$, where $d^r > 0$ is a scale parameter and $\alpha^r \geq 0$ is the demand elasticity, and the marginal cost function is assumed to be linear: $\Psi^{r'}(\bar{H}_t^r) \equiv a^r + b^r \bar{H}_t^r$, where a^r and $b^r > 0$ are the intercept and slope of the marginal cost function.

To summarize, the problem has two state variables, $\{A_t^r\}$, and eight response variables, $\{P_t^r, S_t^r, \bar{H}_t^r, X_t^r\}$, for $r \in \{i, w\}$.

4 Welfare and public costs

The welfare and public costs of policy interventions are evaluated initially based on standard sums of surplus measures of welfare. Given the absence of market imperfections in the laissez-faire model, it is important to note that the introduction of any public policy, such as interventions to reduce price volatility, can be expected to decrease welfare (at least global welfare, as India could possibly improve its welfare at the expense of the RoW by manipulating its terms of trade, as long as other countries did not retaliate). To guide the design of alternative price stabilization policies, an alternative welfare measure, which introduces a preference for reducing price risk, is used.

The public costs of the food security policy include the cost of public storage, the cost of trade policy, and the cost of the PDS, as well as a combination of these costs. The distinction between storage and PDS costs is important. The quantity of grain that is stored and not released domestically is a choice that affects market prices by changing the quantity of grain entering the market. The quantity of grain purchased for resale to low-income consumers has a quite different effect. It exerts an impact on domestic prices only to the extent to which the redistribution from taxpayers to poor consumers results in an increase in aggregate demand

for grain. By making this distinction, it is possible to identify the cost of food subsidies and understand how that cost is affected by trade and storage policies.

4.1 Standard welfare measure

A standard measure of instantaneous welfare, w_t^r, is provided in each country by the sum of consumers' surplus, producers' surplus, and private stock holders' surplus, minus the cost of stabilization policies:[6]

$$w_t^r = -d^r \frac{P_t^{r\,1+\alpha^r}}{1 + \alpha^r} + P_t^r \bar{H}_{t-1}^r \epsilon_t^r - a^r \bar{H}_t^r - \frac{b^r \bar{H}_t^{r\,2}}{2} + P_t^r S_{t-1}^r - (k^r + P_t^r) S_t^r - Cost_t^r, \qquad (7)$$

where $Cost_t^r$ is the cost of stabilization policies, described below. Using (5), equation (7) can be simplified to

$$w_t^r = -d^r \frac{P_t^{r\,1+\alpha^r}}{1 + \alpha^r} + P_t^r A_t^r - a^r \bar{H}_t^r - \frac{b^r \bar{H}_t^{r\,2}}{2} - (k^r + P_t^r) S_t^r - Cost_t^r. \qquad (8)$$

The costs associated with India's stabilization policies are expressed as the sum of storage and trade costs, defined as:

$$Cost_t^i = Cost_t^{i,S} + Cost_t^{i,Tr}. \qquad (9)$$

4.2 A welfare measure including preference for food price stability

As the laissez-faire model in the previous section does not include any market imperfections, the standard surplus-based welfare measure does not take into account any preference for food price stability. To account for it, a quadratic term in the domestic price is introduced into the welfare measure for India:

$$w_t^i = -d^i \frac{P_t^{i\,1+\alpha^i}}{1 + \alpha^i} + P_t^i A_t^i - a^i \bar{H}_t^i - \frac{b^i \bar{H}_t^{i\,2}}{2} - (k^i + P_t^i) S_t^i - Cost_t^i - \frac{K}{2} (P_t^i - \bar{P}^i)^2, \qquad (10)$$

where $K \geq 0$ is a parameter characterizing the social preference for price stability and $\bar{P}^i$ is a target price around which the Government of India wishes prices to be stabilized. $\bar{P}^i$ is taken to be the steady-state, laissez-faire price—the price when shocks are equal to their expectations and when countries do not use storage and trade policies.

Although the quadratic term is merely a means of introducing (in a tractable way) additional concavity in the social welfare function, it can also be given some micro-

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[6] Consumers' surplus is derived as $CS = \int_P^{\bar{P}} D(p) \mathrm{d}p = [d\, p^{1+\alpha}/(1 + \alpha)]_P^{\bar{P}} = d\,(\bar{P}^{1+\alpha} - P^{1+\alpha})/(1 + \alpha)$, so abstracting from the term in $\bar{P}$, which is independent from policy choice, leads to the expression used in the social welfare function.

foundations by being interpreted as the second-order approximation of the difference between the equivalent variation of a risk-averse consumer and its surplus, so it would be the welfare term accounting for non-zero risk aversion and income elasticity. Following Turnovsky, Shalit, and Schmitz (1980), K would in this case be equal to $\gamma(R - v)D^i(\bar{P}^i)/\bar{P}^i$, where γ, R, and v are, respectively, values at steady state of the commodity budget share, risk aversion relative to income risk, and income elasticity. K would be positive if risk aversion is higher than income elasticity, which seems reasonable for staple food products. This would represent an approximation of social welfare for an incomplete-market economy in which risk-averse consumers cannot insure against food price risk (see Gouel and Jean, 2014, for such an interpretation). This interpretation is useful for choosing reasonable values for K.

4.3   Cost of the PDS

The cost of the PDS is assessed here as the direct cost of the subsidies in the PDS, measured as the difference between the open-market price at the time and the subsidized price at which grains are released through India's Fair Price Shops. This cost abstracts from the direct costs of the scheme, such as administrative costs, costs of transport to final consumers, or any costs associated with leakages or fraud—all of which are outside the scope of the model used. The cash flow of the PDS subsidies is equal to the distributed volumes times the difference between market and subsidized prices:

$$\sum_k V_k\big(P_t^i - P_k^{PDS}\big),\tag{11}$$

where the different categories of households benefiting from the PDS—households above the poverty line (APL), below the poverty line (BPL), and the "poorest of the poor" households receiving grain subsidized under the Antyodaya Anna Yojana (AAY) scheme—are indexed by $k \in \{APL, BPL, AAY\}$; V_k is the distributed volume; and P_k^{PDS} the subsidized price. Consistent with the modeling of stock releases in Section 5.1.1, V_k are assumed to be constant and sum to Θ, the total volume released through the PDS. The values can be found in Table 1.

Table 1. Values used to assess the cost of subsidies in the PDS

	Above the poverty line	Below the poverty line	Antyodaya Anna Yojana
Subsidized price, P_k^{PDS} (Rs/t)	6,100	4,150	2,000
Share of volume released, V_k (% of Θ)	51	32	17

Source: Food Corporation of India.

The measured costs of the PDS do not appear in the national welfare measure, since it is considered to be a pure transfer that does not affect the overall economic welfare measure used in this representative-agent model. Clearly, the targeted nature of this intervention may

result in a substantial increase in social welfare if the social welfare function attributes greater marginal utility of income to the beneficiaries relative to those paying the costs of the scheme.

5 Price stabilization policies

This section begins by incorporating India's current wheat policies in the analytical model. As noted, these policies target the three main channels for price stabilization—production, storage and trade. Next, the derivation of optimal price stabilization polices is outlined, followed by proposals for some optimal simple rules that might serve as a more realistic, practical policy alternatives. The social welfare outcomes under the optimal simple rules are then compared to those under the fully optimal policies to test how well they perform.

5.1 India's current wheat policies

India's current trade and storage policies are adjusted regularly at the discretion of the government, depending on prevailing market conditions and policy makers' assessment of which changes are required. To analyze the effects of these policies, they are represented in the laissez-faire model as rules that respond to the market context. The model is designed to capture the indicative impacts of current policies rather than to provide precise figures. The following sections describe how the main structural characteristics of current policies are incorporated into the model.

5.1.1 Storage policy and the PDS

Public stocks are built up largely through purchases at the announced MSP. For simplicity, and given that the model focuses on price volatility stemming from production shocks (domestic and foreign), the MSP is assumed to be constant and equal to the steady-state price, which is the price in the absence of shocks—that is, under normal harvest and demand conditions. In the model, the MSP therefore plays the role of a floor price that the government defends through public storage. Public stock accumulation, ΔS^{G+}, is governed by

$$\Delta S_t^{G+} \geq 0 \perp P_t^i - MSP \geq 0. \tag{12}$$

The critical influence on the market is the difference between government stock purchases, ΔS_t^{G+}, and releases under the PDS, ΔS_t^{G-}. Accounting for public stock purchases and releases, the Indian market clearing equation is adjusted as follows with respect to the laissez-faire model:

$$A_t^i + X_t^w + \Delta S_t^{G-} = D^i(P_t^i) + S_t^i + X_t^i + \Delta S_t^{G+}. \tag{13}$$

Volume released for the PDS, denoted Θ, is assumed to be constant and, based on data from the previous decade, equal to 12 million tons per year. The model allows for the possibility that existing public stocks $(S_t^G + \Delta S_t^{G+})$ may not always be sufficient to cover the quantities required for the PDS. If procurement at MSP is not enough to supply the PDS, the

remaining quantities are assumed to come from open-market purchases. Such purchases need not be represented here, because they are analogous to a transfer operated by the government. Stock releases therefore obey the following equation:

$$\Delta S_t^{G-} = \min(\Theta, S_t^G + \Delta S_t^{G+}). \tag{14}$$

Because releases for the PDS are not state-contingent and the MSP tends to be set at a high level, procurement levels are often high relative to requirements. Without a policy for systematic releases above the established stocking norms, the PDS releases alone would not prevent explosive stock levels. As discussed, the government occasionally resorts to exporting grain from its stocks to reduce excessive accumulation and deterioration (Dorosh and Rashid 2013). For that reason, India is assumed to export its public stocks when they reach a certain threshold. These exports are denoted as X^{S^G}. They are defined by:

$$X_t^{S^G} = \max(0, S_t^G + \Delta S_t^{G+} - \Delta S_t^{G-} - \bar{S}^G), \tag{15}$$

where $\bar{S}^G$ is the threshold that triggers public stock exports. Based on past behavior, the government reaches that threshold when the end-of-season stock equals 25 million tons (Figure 1). Since public stocks are not exported at the Indian market price, these exports do not affect the Indian market equilibrium, only the RoW market equilibrium, which is adjusted accordingly:

$$A_t^w + X_t^i + X_t^{S^G} = D^w(P_t^w) + S_t^w + X_t^w. \tag{16}$$

Public storage is an additional state variable of the problem. Its transition equation is

$$S_t^G = S_{t-1}^G + \Delta S_{t-1}^{G+} - \Delta S_{t-1}^{G-} - X_{t-1}^{S^G}. \tag{17}$$

The cash flows at period t of the storage policy are defined by the sum of three terms: the cost of storing for one period, the outlays from wheat purchases and releases, and the benefits from any export of stocks, which gives the following expression:

$$\begin{aligned} Cost_t^{i,S} = \quad & k^i \left(S_t^G + \Delta S_t^{G+} - \Delta S_t^{G-} - X_t^{S^G} \right) \\ & + P_t^i (\Delta S_t^{G+} - \Delta S_t^{G-}) \\ & - X_t^{S^G} \left(P_t^w - \theta_{i,w} \right). \end{aligned} \tag{18}$$

It can be positive or negative depending on whether the government is releasing or accumulating stocks. This formula assumes that stocks are released at the Indian market price, with the loss on sales under the PDS attributed to the PDS. This assumption enables the cost of storage to be disentangled from the cost of food subsidies, which is the difference between the market price and the subsidized price (see Section 4.3).

5.1.2 Trade policy

Through its trade policy for wheat, India appears to have consistently tried to offset short-run world price movements, even as the country's domestic price policy broadly accommodates the long-run trends. Often this outcome is achieved through discretionary decisions to restrict exports or to apply price minima that reduce wheat exports. The model captures the essence of these discretionary trade policy decisions by using a tariff that is adjusted in opposition to short-run changes in world price. The power of the tariff $(1 + \tau)$ is assumed to be captured by an isoelastic model of the relevant border price:

$$T_t^M = \alpha_M \left(P_t^w + \theta_{w,i} \right)^\beta, \tag{19}$$

$$T_t^X = \alpha_X \left(P_t^w - \theta_{i,w} \right)^\beta, \tag{20}$$

where T^M and T^X are the power of the tariffs applied to imports and exports, β is the elasticity of border protection with respect to border prices, and α_M and α_X are scale parameters.

To determine the extent of trade policy interventions, an error-correction model between India's producer price and world price is estimated, and the short-run price transmission elasticity is retained as an estimate of $1 + \beta$ (see Annex 1 for details on the estimation). The estimated elasticity of border protection is equal to –0.76. Over the long term, India's domestic price has fluctuated around the world price without any systematic deviations, so the scale parameters, α_M and α_X, are calibrated such that there is no protection at steady state.

To incorporate these aspects of the trade policy, the trade equations become

$$X_t^w \geq 0 \perp (P_t^w + \theta_{w,i}) T_t^M \geq P_t^i, \tag{21}$$

$$X_t^i \geq 0 \perp P_t^i \geq \left(P_t^w - \theta_{i,w} \right) T_t^X. \tag{22}$$

This trade policy generates the following outlays:

$$Cost_t^{i,Tr} = \begin{aligned}&(T_t^X - 1) X_t^i (P_t^w - \theta_{i,w}) \\ &-(T_t^M - 1) X_t^w (P_t^w + \theta_{w,i}).\end{aligned} \tag{23}$$

5.2 Optimal price stabilization policies

An optimal stabilization policy is designed based on the assumption that government is committed to following a state-contingent policy that maximizes expected intertemporal welfare. Two potential instruments of stabilization are considered: storage and trade. For convenience, the analysis adopts a primal approach by assuming that government takes control of storage and trade, but the resulting behavior could also be achieved through

incentives for private agents. Where government controls storage and trade, in the absence of private stock holders, the terms accounting for stock holder surplus in the social welfare function are actually equal to public storage costs. The remaining public costs (which may be negative) are associated with trade policy, defined by

$$Cost_t^{i,Tr} = X_t^i(\theta_{i,w} + P_t^i - P_t^w) + X_t^w(\theta_{w,i} + P_t^w - P_t^i).$$

(24)

To determine the optimal levels of trade and storage, the government maximizes the expected sum of the discounted instantaneous social welfare function

$$E_0 \sum_{t=0}^{\infty} \delta^t \left[-d^i \frac{P_t^{i\,1+\alpha^i}}{1+\alpha^i} + P_t^i A_t^i - a^i \bar{H}_t^i - \frac{b^i \bar{H}_t^{i\,2}}{2} - (k^i + P_t^i)S_t^i - Cost_t^{i,Tr} \right.$$

$$\left. - \frac{K}{2}(P_t^i - \bar{P}^i)^2 \right],$$

(25)

subject to the constraints imposed by private agents' behavior and market equilibrium—that is, equations (2), (3), (5), and (6). The optimal policy problem is laid out mathematically in Annex 2. The first-order conditions of this problem are derived following the methodology developed in Marcet and Marimon (2011); for details about the method and the interpretation of its first-order conditions, see Gouel (2013a). Solving this optimal policy problem produces storage and trade rules that are contingent on the state of the system. The policy under consideration is under commitment, which implies that at some initial date the government chooses, once and for all, the state-contingent rules. The policy rules corresponding to policies under commitment are generally time-inconsistent, as they would differ from the rules that would be chosen ex post once any effects of the decisions on prior expectations could be neglected. Given the time-inconsistency of the optimal policy, the policy rules depend not only on the two natural state variables (availability in both countries) but also on their past realizations, which are summarized by two lagged Lagrange multipliers in the first-order conditions laid out in Annex 2.

5.3 Optimal simple rules

Gaining an understanding of the best policy options is important, but fully optimal policies have drawbacks. They are highly dependent on the economic setting for which they are optimized, and they are difficult to implement, because they depend on state variables that are model-dependent and not observable (lagged Lagrange multipliers). These limitations are avoided by following the approach of Gouel (2013c) to design optimal simple rules of price stabilization, which are rules of public behavior that provide simple feedback between observable variables and policy instruments, but whose parameters are chosen to maximize welfare. As before, two instruments of intervention—trade and storage policy—are

considered. In the literature, the most popular simple rules are price-band rules, but they are not good candidates for optimal simple rules. They are extremely nonlinear, making the choice of parameters extremely sensitive to the assumed model and its calibration. Their behavior is far from the behavior of an optimal storage policy, and the probability of stockouts and collapse when stocks reach unmanageable levels is very high (for additional discussion of this issue, see Wright 2011 and Gouel 2013c).

Previous studies (Gouel 2013c; Gouel and Jean 2014) have found that optimal storage policies tend to behave similarly to a competitive storage rule. Building on the idea that private stock holders are good at reacting to evolving economic situations but may provide too little stabilization in the absence of intervention, the prospects for a very simple policy to encourage more private storage (specifically, a constant subsidy to private storage in India) are considered here. Such a subsidy should increase stock levels, which in turn would stabilize prices. As noted, the resulting storage rule could also be implemented through public stocks. Accounting for the constant subsidy ζ, the stock holders' arbitrage equation (3) becomes for India

$$S_t^i \geq 0 \perp P_t^i + k^i(1 - \zeta) - \delta E_t P_{t+1}^i \geq 0. \tag{26}$$

To facilitate the interpretation of results, the subsidy is expressed as a percentage of physical storage costs k^i. In this case, the public costs of storage are defined by

$$Cost_t^{i,S} = k^i \zeta S_t^i. \tag{27}$$

In the absence of an upper bound on stock levels, a necessary condition for a stationary rational expectations equilibrium to exist is for storage to be costly. For instance, if price stays constant (that is, at a steady state), storage should not be profitable and so should not take place, which can be stated using equation (26) as

$$\bar{P}^i + k^i(1 - \zeta) - \delta\bar{P}^i > 0, \tag{28}$$

$$\zeta < 1 + \frac{(1 - \delta)\bar{P}^i}{k^i}. \tag{29}$$

This value will be used in the welfare maximization as an upper bound on ζ to ensure convergence to a stationary equilibrium.

Trade policies are assumed to be set following the rule in current use, indicated in equations (19) and (20). However, β, the elasticity of border protection with respect to border price, will be chosen to maximize welfare.

Taking into account the public costs defined by equations (23) and (27), the optimal simple rules are the rules defined by the parameters ζ and β that maximize

$$E_0 \sum_{t=0}^{\infty} \delta^t \left\{ -d^i \frac{P_t^{i\,1+\alpha^i}}{1+\alpha^i} + P_t^i A_t^i - a^i \bar{H}_t^i - \frac{b^i \bar{H}_t^{i\,2}}{2} - \left[k^i(1-\zeta) + P_t^i \right] S_t^i - Cost_t^i \right.$$

$$\left. - \frac{K}{2} \left(P_t^i - \bar{P}^i \right)^2 \right\},$$

(30)

subject to equations (2), (3), (5), (6), (19)—(22), and (26).

6 Results

6.1 Calibration

The model focuses on the stochastic aspects of India's wheat market. The year 2012 is used as the reference point for the steady-state equilibrium, and the values of all variables are set at their 2012 levels. Table 2 describes the steady-state equilibrium values of the main variables.

Table 2. Model calibration values

Calibration target at deterministic steady state		India	RoW
Consumption (million tons)		86.51	589.55
Production (million tons)		86.51	589.55
Price (Rs/t and $/t)		9416.5	200
Parameter	**Economic interpretation**	**India**	**RoW**
$std(\epsilon^r)$	Standard deviation of production shocks	0.035	
δ	Discount factor	0.95	
k^r	Physical storage cost ($/t)	22.4[a]/87[b]	22.4
$\theta_{r,s}$	Export trade cost ($/t)	35	65
E	Exchange rate (Rs/$)	50	
α^r	Demand elasticity	-0.3	-0.12
a^r	Intercept of marginal cost function	-35,873	-761.90
b^r	Slope of marginal cost function	518	1.62
MSP	Minimum support price (Rs/t)	9416.5	
$\bar{S}^G$	Stock threshold for exports from public stocks (million tons)	25	
Θ	Volume released for PDS (million tons)	12	

Note: Consumption and production targets are obtained as the trend value in 2012 after HP filtering (smoothing parameter of 400) on the underlying data from USDA (2013). The standard deviation of production shocks is determined as the standard deviation of filtered production values.
[a] For private storage.
[b] For public storage.

At the steady state, India is self-sufficient, and no trade occurs with the RoW. This means that India's prices will oscillate between cif and fob prices, depending on the occurrence of domestic and foreign production shocks. Recently India's domestic price has been close to and occasionally below the fob price. To reflect the fact that on average India is more likely to export rather than to import, the steady-state price is calibrated closer to the fob price than the cif price.

Based on detrended production, the random component of wheat production is estimated to have a standard deviation of 0.035 in both regions, and to be independent across time and space. The equality of production variability between the RoW composite and the single country of India is unusual and likely reflects the diversity of production regions within India and the fact that almost all of India's wheat is grown under irrigation. In general, the volatility of output would be expected to be much higher for an individual country than for the RoW composite, because of the low correlations between the outputs of different countries.

Annual interest rates are assumed to be the same for each region, at 5%. Choosing appropriate storage costs is important, as this variable significantly affects the results. For private stock holders in India and in the RoW, per unit storage charges are assumed to be US$ 22.40 per ton, based on estimates of worldwide benchmark private sector costs from a recent World Bank study (World Bank and FAO 2012).[7] Combined with the opportunity cost of the grain, this physical storage cost entails an overall storage cost at steady state of 17.5% of India's domestic price. Public storage costs in India appear to be much higher, at around US$ 87 per ton,[8] but these costs are likely to be underestimated because they neglect the cost of storage losses. Anecdotal evidence appears to indicate that such losses are large because storage conditions are inadequate,[9] but the actual rate at which stocks deteriorate is unknown. For private storage costs, following (29), the maximum storage subsidy compatible with a stable steady state is equal to 1.4. Similarly, for public storage costs of US$ 87 per ton, the maximum subsidy is 1.1.

Indian import costs are based on international trade costs and port charges from Pursell, Gulati, and Gupta (2009). For export costs, the port charges are the same as for imports, but international trade costs are assumed to be smaller (2/5), as India exports wheat to less distant countries than those from which it sources its imports (Pursell, Gulati, and Gupta 2009 do not provide information on export costs). These trade costs exclude domestic transport costs. The

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[7] Private storage costs in India are competitive relative to the global benchmark used here. Estimates of storage costs from National Bulk Handling Corporation, a private entity, are equivalent to about US$16 per ton in general, but a bit higher at about $19.2 in the National Capital Region or port locations (Anil Choudhary, Managing Director and CEO, *personal communication)*. Data from IFC from recent modern grain silos projects indicate a cost of storage at about US$ 19.75 per ton in Punjab, where the private developer of storage provides land, and $11.5 per ton in Madhya Pradesh, where land is provided by the government. The Food Corporation of India has fixed ceiling rates for storage rental from private providers under the "Private Entrepreneurs Guarantee" (PEG) scheme at Rs 4.78 per quintal per month, which translates to only US$ 9.56 per ton (see Department of Food and Public Distribution website at http://dfpd.nic.in/?q=node/34). Finally, the base storage rental rates established by the Central Warehousing Corporation for private sector bidding for wheat storage under normal access conditions (that is flat terrain with easy access such as may be expected in the national capital region) are about US$ 18 per ton (see http://www.cewacor.nic.in/Docs/commodity_tariff_2013-14.pdf).

[8] The economic cost of the Food Corporation of India available at http://fciweb.nic.in/finances/view/9, accessed May 12, 2014. For the financial year 2012/13, the annual rate of buffer stock carrying cost is estimated to be Rs 4,744.6 per ton. The average exchange rate from April to March was 54.35 Rs/US$, which leads to an annual storage cost of US$ 87.3 per ton.

[9] "As crops rot, millions go hungry in India," Reuters, July 1, 2012; "2,400 MT wheat rotting in govt granaries for past 2 years," The Times of India, May 7, 2013.

exchange rate plays no role in the model; it serves only to present the results and is set at Rs 50 Rs per US\$ 1, which is the exchange rate that prevailed in early 2012.

The selection of appropriate elasticities is challenging—the literature is uncertain on this point—but crucial, as they drive many results. The literature on commodity price dynamics, which implies relatively low demand elasticities (Cafiero et al. 2011; Roberts and Schlenker 2013), puts the RoW demand elasticity at –0.12. An elasticity this low is unlikely to be valid for a lower-middle-income country such as India, however, where demand for this staple food is expected to be more elastic than the world average (Muhammad, Seale, and Regmi 2011). Based on recent estimates by Kumar et al. (2011), a price elasticity of –0.3 was ultimately selected.

The supply elasticity at steady state is 0.2, in line with the commonly used supply elasticity for wheat. The combination of this elasticity and of target values of price and production at steady state makes it possible to determine a^r and b^r. The rational expectations storage model is approximated numerically (see Annex 3, for details).

To evaluate social welfare and to design optimal policies, a weight is assigned to wheat price volatility in the social welfare function. No ready source of information is available for this policy parameter. As explained in Section 4.2, the parameter characterizing the social preference for price stability, K, could be interpreted as a second-order approximation of the equivalent variation for a risk-averse consumer, reflecting income and risk-aversion effects. This interpretation is used to guide the choice of relevant values, and consumers are assumed to spend 10% of their income on wheat. The steady-state values are used as the reference levels for demand and price. In seeking to define optimal policies, several values will be considered for K to illustrate how policies vary when different welfare weights are assigned to price volatility. The difference between the parameters of relative risk aversion and income elasticity $(R - \nu)$ are varied from 0 to 12. In unpacking current policies (6.2) and exploring fully optimal policies (6.3), the analysis retains $R - \nu = 6$.

6.2   Unpacking current policies

This section characterizes the effects of the current storage and trade policies described in Section 5.1. Three scenarios are considered as alternatives to laissez-faire: a scenario with storage policy alone, a scenario with trade policy alone, and a scenario combining both policies. These policy experiments make it possible to unpack the contribution of each policy. The experiment relying only on storage policy assumes that India liberalizes its wheat trade, including the use of export subsidies to dispose of excess stocks. Similarly, the trade policy assumption implies no public storage.

In interpreting the results that follow, a word of caution is in order regarding the limitations of rational expectations storage models with respect to what they aim to represent and how well they achieve that aim. First, the only motivation for private storage assumed here is intertemporal arbitrage. While that is an important motive per se, it excludes many other important transactional or precautionary motives that could explain much actual stock-holding behavior (Williams 1986). Given that trade is instantaneous in the model, there is also no reason to accumulate stocks to account for time to ship (Coleman 2009). These motivations are quantitatively important, as evidenced by historical stock data. A purely speculative motive would allow for regular stockouts, while at the world level the stock-to-use ratio never decreases much below 20%. Because of this focus on one motive for storage, the simulated statistics on private stock levels are likely to underestimate real storage. Second, stabilization policies are represented as free of any flaws (except potentially in their design): The policies perfectly follow the decided rules without any delay or discretionary political interventions. Such a perfect representation of India's wheat policies is likely to overestimate the achievable price stabilization. Third, for the sake of tractability, the model focuses on two main sources of price volatility: production shocks in India and in the RoW. This focus excludes other sources of volatility such as shocks to exchange rates, and prices of oil and other agricultural commodities. Overall, the model aims to capture the most important types of spatial and intertemporal arbitrage, but the inherent complexity of this issue implies that the model should not be considered a forecasting tool but rather a means of quantitatively illustrating the consequences of each policy option.

Table 3 presents the effects of the various instruments of current policy on the asymptotic distribution of the model.[10] Storage and trade policies alone provide similar levels of price stabilization, with storage decreasing the coefficient of variation a little more than trade policy. The ability of storage to achieve such price stability in an open economy comes from the fact that India's domestic price is often between the fob and cif margins. This assessment is confirmed by the fact that world price volatility is little affected by a storage-only policy. The fundamental difference between the stability provided by trade and storage concerns extreme prices. The storage policy truncates low prices almost perfectly, but it cannot prevent all price spikes and does little to reduce the occurrence of high prices. The explanation for this outcome lies with the rule governing the storage policy. The policy is not designed to operate as a price band, with stocks released to prevent high prices; rather, stocks are released in a fixed amount every period to supply the PDS. In contrast, the trade policy mostly truncates high domestic prices. Together both policies are extremely effective in stabilizing the domestic price, because of the complementarity between the instruments. Trade policy

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[10] See Annex 3 for details about the simulation method.

prevents public stocks from being exported when the world price spikes, preventing any leakage from the operation of the storage policy to the world market.

Table 3. Unpacking current policies, statistics (quantities in million tons)

Variables	Laissez-faire	Trade policy	Storage policy	Both instruments
India price (Rs/t)				
Mean	9,809	9,527	9,882	9,486
CV (%)	14.39	10.68	10.12	3.13
Quantile 10%	8,223	8,307	9,417	9,417
Quantile 90%	11,544	10,910	11,085	9,417
RoW price (US$/t)				
Mean	200.5	202.3	199.7	202.5
CV (%)	20.70	23.99	19.57	23.28
Quantile 10%	160.2	160.2	159.8	160.3
Quantile 90%	258.8	269.2	251.6	272.3
India demand				
Mean	85.77	86.39	85.41	86.33
CV (%)	3.98	3.11	2.58	0.84
Mean India production	87.13	86.66	87.37	86.62
Mean India storage				
Private	0.10	0.02	0.00	0.00
Public			4.21	10.38
Mean RoW private storage	4.05	4.78	3.69	4.75
Mean exports	1.38	0.27	1.96	0.18
Mean imports	0.02	0.00	0.01	0.00

The policies have little effect on India's wheat production. Since producers are assumed to be risk neutral in their behavior and their marginal cost linear in the production level, their production decisions depend not on price volatility but on the expectations of prices times the yield shock (equation (2)), which vary little between the policies considered, as evidenced by the mean price changes.[11]

Under all scenarios, the model allows for the possibility of competitive domestic storage in India. In practice, stock holders find few profit opportunities under scenarios that include active trade and storage stabilization policies, since these policies rarely allow speculators to cover their costs. A significant level of private storage arises only when both storage and trade policies are removed. These policies do have an effect on private storage in the RoW, however. By increasing world price volatility, the trade policy option increases the profit opportunities from speculation and raises the mean stock level. The storage policy crowds out part of foreign storage, as it diminishes world price volatility slightly. The combination of the two policies is dominated by the effects of the trade policy and storage increases worldwide.

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[11] This result is confirmed in a context of risk-averse producers; see Annex 4. India's wheat production is largely unaffected by the stabilization policies, unless producers are assumed to have a very high level of risk aversion.

Public stocks reach a much higher level when storage policy is combined with trade policy. This outcome is explained by the high degree of insulation permitted by trade policy. Combined with a trade policy of this type, public stock accumulation is almost perfectly insensitive to foreign availability, since the foreign price does not influence the domestic price. Storage releases for the PDS are constant and do not differ across scenarios. Only the releases for direct export to dispose of excessive stocks differ, as they are not allowed in the storage-only policy. For that reason, differences in average stock levels are explained by the levels of stock accumulation. Without trade policy, Indian domestic prices are often driven above the intervention price (equal to the steady-state price) by foreign demand. Counter-cyclical adjustments of trade policies prevent this from happening and trigger frequent public storage interventions to defend the MSP. In this situation, which is not far from that of a closed economy, defending a floor price equal to the steady-state price is sure to lead to very large stocks.

These differences in stock levels translate to large differences in government outlays. The discounted average cost of a storage policy alone is US\$ 382 million, while it is US\$ 874 million when combined with trade policy (Table 4). Table 4 also displays the 5th and 95th percentiles of the corresponding annual cash flow. The cash flow for the storage policy is alternatively positive or negative depending on changes in stock levels. In both situations, 5% of the time, the accumulation of public stocks costs more than US\$ 2,021 million. The storage policy is much more costly than the trade policy. On average, trade subsidies are compensated by taxes, and trade is so much reduced by these interventions that actual outlays are low.

The cost of the PDS subsidy revolves around US\$ 1,150 million but varies considerably with the domestic price. Price stabilization policies clearly help to stabilize costs of the PDS; in the absence of these policies, the cost of the PDS could increase two-fold from one year to the next.

Table 4 also decomposes the welfare results for each component. Welfare components are expressed as deviations from laissez-faire and normalized as a percentage of the steady-state value of consumption of the corresponding country. Notably, when both policies are combined, storage costs reach on average 3.7 percent of the commodity budget share. Without retaining a very high weight given to food price stability, this cost is likely to exceed gains from lower price instability.

Before analyzing optimal policies, it is important to understand the behavior of private stock holders in laissez-faire, as the simple rules consist of incentivizing them to store more. The first panel of Figure 3 represents the storage rules that are applied depending on the availability of wheat in the RoW. To facilitate interpretation, the five values of RoW availability selected correspond to 95%, 100%, 105%, 110%, and 115% of steady-state availability. For a RoW availability that is 5% less than normal (560 million tons), nothing is

stored in India, because global scarcity drives the price too high to make storage profitable. Some private storage occurs when RoW availability is at the steady-state level (590), but the marginal propensity to store (out of domestic availability) in this situation is between 0.36 and 0.50, which is much lower than for higher availability. This result is explained by the coexistence of private storage and exports. When domestic availability increases, it is either exported, consumed, or stored. At a higher level of RoW availability (619—678), there is no competition with exports, so the marginal propensity to store is higher. Private storage in India reacts nonlinearly to RoW availability. Starting from low RoW availability, Indian stocks tend to increase with global availability. When RoW availability is plentiful, the additional availability translates into additional RoW stocks, which depress expected prices and thus storage in India. It is interesting to note that storage becomes positive for levels of domestic wheat availability around 90 million tons, significantly above the steady state equal to 86.51.

Table 4. Welfare changes and public cost of current policies

| Variable	Laissez-faire	Trade policy	Storage policy	Both instruments
		Welfare changes as percentage of consumption value		
India welfare				
Consumers' surplus		2.43	-1.34	2.14
Producers' surplus		-2.65	1.42	-2.22
Total cost		0.08	-2.18	-3.62
Storage cost[a]		0.00	-2.18	-3.74
Trade cost		0.08	0.00	0.13
Cost of volatility (for $R - \nu = 6$**)**		0.39	0.31	0.66
Total welfare		0.24	-1.80	-3.04
RoW welfare		-0.01	0.01	-0.01
		Cost of the policies on the asymptotic distribution (million US$)		
Storage policy				
Mean	0	0	382	874
Quantile 5%	0	0	-1,322	-595
Quantile 95%	0	0	2,021	2,659
Trade policy				
Mean	0	-13	0	-26
Quantile 5%	0	-72	0	-160
Quantile 95%	0	6	0	64
PDS subsidy				
Mean	1,201	1,140	1,225	1,131
CV	28.50	21.37	19.46	6.31
Quantile 5%	777	801	1,084	1,101
Quantile 95%	1,820	1,594	1,715	1,227

[a] Using public storage costs.

In contrast, for a given level of domestic availability, public stocks accumulate much more than private stocks (not displayed in Figure 3). When the domestic price reaches the MSP, the government is compelled to buy all the wheat offered for procurement. In

consequence, the marginal propensity to store is equal to one until stocks reach the threshold that triggers exports from public stocks, while in laissez-faire the marginal propensity of private stock holders to store does not exceed 0.8. Since public stock accumulation is only a function of domestic availability and does not depend on previously accumulated stock, except for the direct exports, such a storage policy would be explosive: Public stocks would grow infinitely.

It is also worth noting that since the trade policy insulates the domestic market from the RoW, public stock accumulation mostly reacts to domestic and not worldwide availability. One consequence is that a large accumulation of public stocks may coexist with export restrictions, which could be interpreted as the simultaneous application of both the brake and the accelerator—the price is lowered by the export restrictions and raised by the stock accumulation. This combination is not problematic in itself, however, because it can arise as an outcome of optimal trade and storage policies (Gouel and Jean 2014). In the Gouel and Jean framework of a small economy, this combination occurs at medium world price levels because stock accumulation does not increase the domestic price when the country is exporting, and the subsequent release of stocks will cause prices to fall in periods of scarcity.

Figure 3. Storage rules followed by Indian private stock holders in the laissez-faire model and under simple rules for various levels of availability in the rest of the world
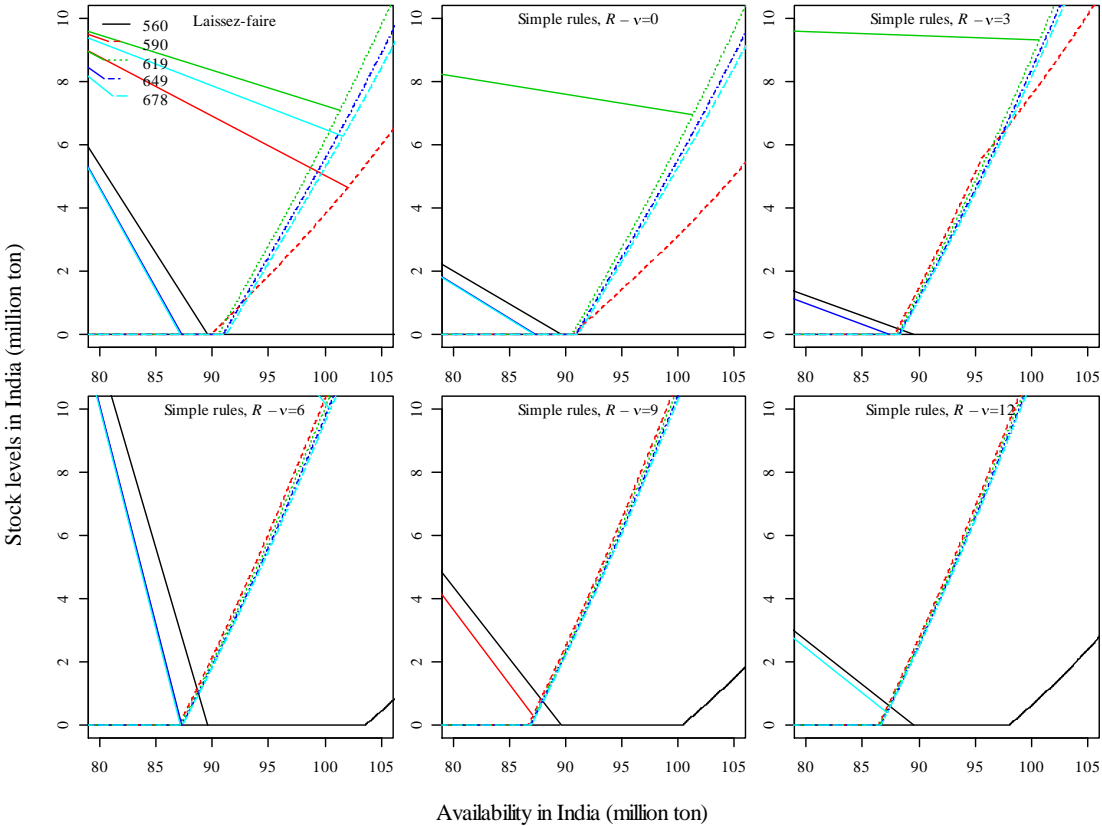
In the present framework, however, the combination of export restrictions and stock accumulation is more likely to create problems. Insulated from the world price, stock accumulation does not respond to global market conditions, allowing stocks to accumulate even as the price spikes in the RoW. In addition, in the absence of effective release rules, the accumulation of stocks does not guarantee more stable future prices.

6.3 Optimal policy versus simple rules

This section compares outcomes under the laissez-faire model, the application of an optimal policy, and the use of optimal simple rules. Because the costs of public storage are very high in India, it is challenging to find a role for storage in an optimal stabilization policy. Here it is assumed that grain is stored by private agents, and the precise stock level is optimally decided. The issue of optimal storage at a high public cost is left for discussion in Section 6.4.

Total welfare gains for India under the optimal policy represent 0.46% of the value of steady-state wheat consumption in India (Table 5). When compared with the optimal policy, the optimal simple rules prove to be very good, achieving 86% of the welfare gains of the optimal policy. One important difference between the results of these policies is that under the optimal policy, the coefficient of variation of price in India is almost four percentage points lower than under simple rules, despite similar stock levels.

Table 5. Optimal policy versus simple rules for $R - \nu = 6$ (quantities in million tons)

Variable	Laissez-faire	Optimal policy	Simple rules
India			
Mean price (Rs/t)	9,809	9,544	9,583
Price CV (%)	14.39	4.78	8.53
Mean stock	0.10	0.95	0.95
Mean exports	1.38	0.85	0.62
Mean imports	0.02	0.32	0.00
RoW			
Mean price (US$/t)	200.5	201.9	201.7
Price CV (%)	20.70	22.69	22.48
India welfare			
Consumers' surplus		1.66	1.70
Producers' surplus		-1.79	-1.84
Total cost		0.02	0.05
Storage cost		-0.09	-0.12
Trade cost		0.11	0.17
Cost of volatility		0.57	0.49
Total welfare		0.46	0.40
RoW welfare		*-0.01*	*-0.01*

Under simple rules, private storage is incentivized by a constant subsidy equal to 97% of physical storage costs. Under optimal policy, the government controls storage, but it is possible to determine the state-contingent subsidy that would make private stock holders behave similarly to the optimal policy. The optimal state-contingent subsidy would be above

100%, close to steady state, but could fall below 97% when availability in India falls below steady state. The subsidy decreases with domestic or foreign availability, because in a context of scarcity it is better to let producers increase the production level than to incentivize stockpiling.

The simple-rules trade policy is counter-cyclical to border price, with an optimal constant elasticity of –0.49, and adjusts similarly for exports and for imports. Compared to the laissez-faire arrangement, the simple-rules trade policy has a strong anti-trade bias, significantly reducing exports and imports. The optimal trade policy does not restrict trade as much; it reduces exports but increases imports. By design, the optimal trade policy is a function of both world and domestic availability, not just world price, as under the simple-rules policy. In consequence, instead of just insulating India from the world market, the optimal policy exploits the world market to increase domestic stability, resulting in increased imports. With this policy, imports may be subsidized to decrease the domestic price when domestic availability is low, whereas imports are subsidized under the simple-rules policy only when the world price spikes.

Despite these limitations, the simple-rules policy does very well, achieving almost all of the welfare gains offered by the optimal policy. The good performance of the simple rules is not limited to the specific value of K. Table 6 shows that for other positive weights given to price stability in the welfare function, simple rules achieve a high share of the gains from the optimal policy. Since policies under simple rules are easier to analyze and to implement than optimal policies, the remaining discussion will focus on the simple-rules policies.

6.4   Optimal simple rules of stabilization

The optimal simple storage policy allows for two interpretations. In the most obvious one, government provides incentives to private stock holders through the constant subsidy. Another interpretation is that the optimal storage subsidy also provides a storage rule that could be implemented by a public authority such as the Food Corporation of India, although (as noted in the calibration) storage costs are much higher for public than for private storage. For that reason, optimal storage will differ depending on whether it is undertaken by the private sector or by a public agency. The following sections seek to determine the optimal policies for both configurations, but the emphasis is on privately operated storage, given that it is much more cost-effective.

6.4.1   Storage by private stock holders

For $R - v = 0$, no weight is assigned to price volatility in social welfare. This choice does not imply that the optimal policy is free trade, because India can improve its social welfare by manipulating its terms of trade. For the trade policy, the chosen simple rule is not particularly suited to maximize welfare by manipulating the terms of trade. Export or import subsidies

would not make sense, because both lead to a deterioration in the terms of trade. Following Bagwell and Staiger (1990), a trade policy aimed at exploiting the terms of trade should be based on the potential trade volume, and thus on the difference between Indian and RoW availability, rather than on RoW price. Although the simple rules are not designed to take into account the motivation for terms-of-trade manipulation, trade interventions are not negligible when price volatility is unweighted (see Table 6, first column). The optimal elasticity of border protection (β) is –0.17, which already reduces price volatility from 14.39% in laissez-faire to 12.77%. The optimal storage subsidy (ζ) is low, equal to 2% of physical storage cost. One interpretation for this non-zero storage subsidy is that an increased storage level could lead to more exports and so to larger potential gains from terms-of-trade manipulation.

Table 6. Optimal simple rules when private agents hold stocks (quantities in million tons)

	R-v				
Variables	0	3	6	9	12
Insulation parameter (β)	-0.17	-0.41	-0.49	-0.53	-0.55
Storage subsidy (ζ)	0.02	0.72	0.97	1.08	1.15
Share of welfare achieved by optimal simple rules (%)	77.8	85.8	86.3	86.1	85.7
India					
Mean price (Rs/t)	9,728	9,614	9,583	9,570	9,564
Price CV (%)	12.77	9.91	8.53	7.76	7.16
Price quantile 10%	8,232	8,632	8,818	8,906	8,972
Price quantile 90%	11,343	10,954	10,769	10,644	10,544
Mean stock	0.08	0.48	0.95	1.31	1.68
Mean exports	1.09	0.73	0.62	0.56	0.53
Mean imports	0.01	0.00	0.00	0.00	0.00
RoW					
Mean price (US$/t)	201.0	201.5	201.7	201.9	202.0
Price CV (%)	21.40	22.25	22.48	22.59	22.62
Mean stock	4.21	4.44	4.47	4.48	4.49
India welfare					
Consumers' surplus	0.64	1.53	1.70	1.77	1.80
Producers' surplus	-0.72	-1.68	-1.84	-1.91	-1.94
Total cost	0.10	0.11	0.05	0.01	-0.04
Storage cost	0.00	-0.05	-0.12	-0.17	-0.22
Trade cost	0.10	0.16	0.17	0.18	0.18
Cost of volatility	0.00	0.21	0.49	0.79	1.10
Total welfare	0.02	0.17	0.40	0.66	0.92

When a positive weight is given to price stability in India's social welfare function, the optimal simple rules provide significant price stability. The two parameters that characterize the rules, β and ζ, increase significantly for the initial departures from a zero weight on volatility, but they progressively flatten as the risk weight is further increased. It follows from their limited progression that price volatility decreases only slightly once $R - v$ exceeds 9. The implications are shown by calculating the cost of the policy and the welfare gains from price stabilization. The mean stock level and the cost of storage increase linearly with the preference for price stability (Table 6), while price volatility decreases at a much slower rate.

The effect of storage policy on price stability decreases with existing stock levels, because stocks have to be held for longer and to be bought at higher prices.

From the observation of the 10 and 90% quantiles, the price stabilization achieved by the optimal simple rules appears to provide some protection from very low and very high prices. In laissez-faire, the 10% price quantile is equal to 87.3% of the steady-state price, while under optimal simple rules, for $R - \nu = 6$, it is equal to 93.6% of the steady-state price. Such a policy will provide farmers significant protection from low prices.

The average stock levels for India in Table 6 are low relative to current stock levels. However, it is important to remember that these stock levels are end-of-year stock levels, rather than the within-year stocks that are frequently discussed. The stock level of 1.68 million tons for the highest level of stabilization appears comparable with the norm of 4 million tons for buffer stocks of grain recommended in the 2003 technical report (Chand and Birthal 2011, p. 4), assuming that this buffer stock is around two-thirds rice and one-third wheat. Within year stock levels are predominantly working stocks, rather than the buffer or reserve stocks that are considered in the annual model used in this paper. The results from the model might be expected to be below those generated by norms for buffer stocks based on observed crop yield shortfalls, such as those derived by Chand and Birthal, because the policy considered here uses trade as well as storage policies to manage price volatility.

Figure 3 permits a comparison of storage behavior under laissez-faire and optimal simple rules. Each panel of the figure represents the private storage rules for various levels of availability in the rest of the world. Overall storage behavior is identical under optimal simple rules and laissez-faire, but the simple rules affect the stockout limits, the marginal propensity to store, and the reaction to world price. As shown in Table 6, in the absence of preference for price stability (top-middle panel of Figure 3), stock levels decrease slightly because the price stabilization coming from trade policy interventions is not compensated by a significant storage subsidy. With preference for price stability, the stockout limits (defined as the levels of domestic availability at which all private stocks are sold) decrease when K increases. In laissez-faire, the stockout limit is close to 90 million tons, while for $R - \nu = 12$ it is close to the steady-state consumption level of 86.51 million tons. In that case, private stock holders start accumulating stocks as soon as normal consumption is satisfied, while in the absence of public intervention storage starts at a much higher level of availability.

The second effect of optimal simple rules is that they tend to increase the marginal propensity to store out of domestic availability. The storage curves are also much less influenced by RoW availability in the presence of public intervention. The increased marginal propensity to store is explained by the storage subsidy, while the decreased sensitivity to world price is explained by the trade policy interventions. Since those interventions insulate

India from RoW price changes, domestic storage tends be less sensitive to foreign conditions. This point is also clear in the top-right panel for $R - v = 3$. When RoW availability is equal to 590 million tons, India exports for high domestic availability, as reflected in the storage rule that has a lower marginal propensity to store than for higher RoW availability. Under simple rules, however, the marginal propensity to store while exporting is much higher than it is under laissez-faire as a result of the trade policy interventions.

One consequence of the optimal simple rules is a shift in the distribution of domestic availability to the right (see Figure 4, left panel) relative to the situation under laissez-faire. Not only does the average level of availability rise but the distribution becomes more dispersed, with a higher probability of availability outcomes above the mean. These changes in availability help to stabilize domestic prices as reflected in the concentration of its density around the mean (Figure 4, right panel). The combined policy reduces the probability of both high and low price outcomes but is more effective in managing the low price shocks (which can be fully absorbed using storage alone) than in reducing high price shocks (for which trade policy is more effective).

Figure 4. Asymptotic densities of availability and price in India under laissez-faire and optimal simple rules
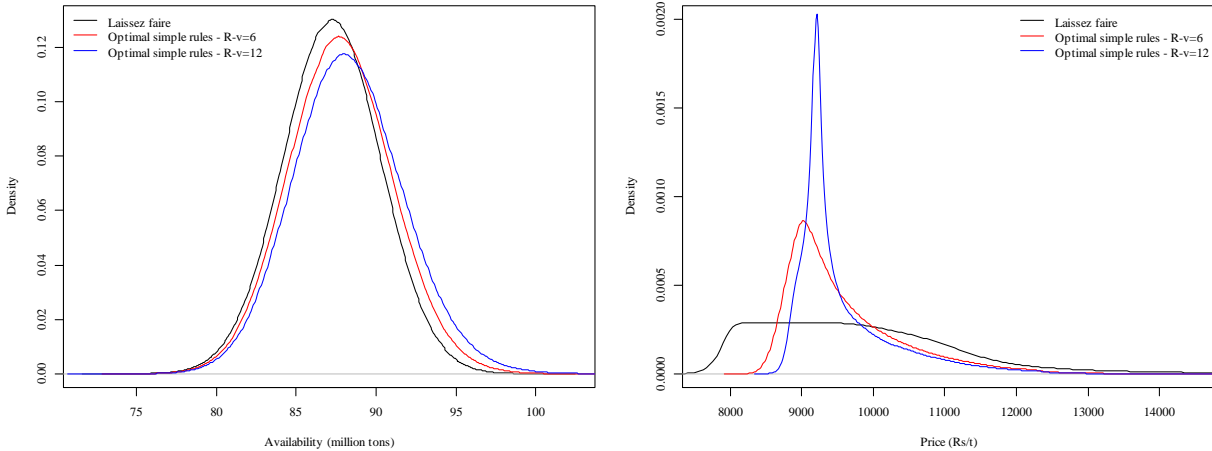
To illustrate the complementarity between the two instruments, Table 7 displays statistics on Indian prices and the parameters of the policy rules when instruments are optimized separately. The price stability achieved by using the policy instruments separately is much lower than when they are combined. The optimal coefficient of insulation from world price, β, is very close to its value when combined with storage. This is not the case for the subsidy to private storage, which is lower than when combined with trade policy. This lower value can be explained by two things. First, by reducing domestic price volatility, the trade policy reduces the incentives for private storage; these lower incentives are compensated by the subsidy to storage when both instruments are used, but this compensation is not needed when using storage policy alone. Second, the benefits from the storage policy leak to the world

market without trade policy, reducing the benefits compared to those from a combined intervention.

Table 7. Optimal simple rules when instruments are considered separately

	R-v				
Variables	**0**	**3**	**6**	**9**	**12**
	Optimal trade policy (when $\zeta = 0$)				
Insulation parameter (β)	-0.17	-0.40	-0.48	-0.52	-0.56
India price					
Mean (Rs/t)	9,728	9,631	9,602	9,587	9,575
CV (%)	12.79	11.24	10.92	10.79	10.71
RoW price					
Mean (US$/t)	201.0	201.6	201.8	201.9	201.9
CV (%)	21.40	22.40	22.75	22.95	23.13
	Optimal storage policy (when $\beta = 0$)				
Storage subsidy (ζ)	-0.09	0.49	0.73	0.85	0.93
India price					
Mean (Rs/t)	9,809	9,802	9,805	9,815	9,823
CV (%)	14.46	13.61	12.85	12.28	11.85
RoW price					
Mean (US$/t)	200.5	200.3	200.2	200.1	200.1
CV (%)	20.72	20.56	20.41	20.27	20.16

6.4.2   Storage by a public agency

If the agent receiving the storage subsidy is a public agency, the results are very different. The combination of a storage cost of US$ 87 per ton and a 5% interest rate implies at steady state an overall cost to store for one year equal to 53.5% of the price. A private stock holder with these high costs would not carry any stocks in laissez-faire in the absence of a storage subsidy. Indeed, it is not possible to break even with such high storage costs.

In this scenario, results depend on maintaining the assumption that private stock holders are authorized to operate (without subsidy) alongside the public agency. If they are authorized to operate, it is optimal to not subsidize public storage, and the results are identical to the results obtained from the optimal trade policy alone in Table 7. In the absence of private stock holders, it is optimal to subsidize storage, but the overall level of storage remains very small because its high cost discourages its use as a policy instrument (Table 8)—even with significant storage subsidies (between 60% and 77% of storage cost). These subsidies are just sufficient to make public storage profitable but not to induce a significant level of storage. With such high storage costs, it is better for India to rely on trade and private storage abroad than on domestic public storage.

Table 8. Optimal simple rules when stocks are managed by a public agency and private storage is prohibited

Variables	R-v				
	0	3	6	9	12
Public storage cost of US$ 87 per ton					
Insulation parameter (β)	-0.17	-0.40	-0.48	-0.54	-0.57
Storage subsidy (ζ)	0.60	0.62	0.69	0.77	0.77
India price					
Mean (Rs/t)	9,730	9,633	9,601	9,581	9,573
CV (%)	13.03	11.42	11.00	10.69	10.62
RoW price					
Mean (US$/t)	201.0	201.6	201.8	201.9	202.0
CV (%)	21.43	22.41	22.78	23.02	23.15
Mean India stock (million tons)	0.01	0.01	0.02	0.06	0.06
Public storage cost of US$ 40 per ton					
Insulation parameter (β)	-0.17	-0.40	-0.49	-0.54	-0.56
Storage subsidy (ζ)	0.14	0.48	0.83	0.93	1.00
India price					
Mean (Rs/t)	9,730	9,630	9,585	9,563	9,554
CV (%)	13.03	11.18	9.71	8.89	8.22
RoW price					
Mean (US$/t)	201.0	201.6	201.7	201.8	201.9
CV (%)	21.43	22.41	22.62	22.78	22.84
Mean India stock (million tons)	0.01	0.06	0.42	0.69	0.99

Since it is difficult to economically justify public storage at the current high costs, Table 8, also considers what optimal rules would be if public costs were lower at $40 per ton, that is between private storage costs and current public costs. Albeit high, costs at US$ 40 per ton are low enough to justify a significant level of public storage when a sufficient weight is given to price volatility. The amount of storage subsidy is significant, as it covers almost all storage costs, but the insulation parameters are not significantly affected by the change in public storage costs.

7   Conclusions

The analysis presented here has relied on a rational expectations storage-trade model to represent current policies for managing wheat price volatility in India and propose alternative stabilization policies. Representing current policies is a challenge, because they appear to be highly discretionary. To capture their essence, they have been represented as simple rules, defined as functions of world and domestic conditions. The alternative stabilization policies are derived from the maximization of a social welfare function that includes a motivation for price stability. The treatment of alternative policies contains two innovations for developing price stabilization policies: It designs optimal price stabilization policies for a large-country case, and it considers simple rules for stabilization and demonstrates how closely their effects can approximate those of a fully optimal policy.

India's policies have been very effective in stabilizing the domestic wheat price, but their high costs raise concerns about whether the costs are exceeding the benefits. The current policy is costly for two main reasons: Trade and storage policy are not coordinated, and the storage policy appears to follow a buy-and-hold strategy. Large stock levels are held for long periods, but stock releases are insufficient to dampen domestic price rises; instead, the government has occasionally had to dispose of wheat stocks on the world market.

Another key food policy issue for India is the cost of public grain storage. The current costs, declared by the Food Corporation of India, are four times higher than long-run costs estimated for other countries by the World Bank and Food and Agriculture Organization (FAO) (2012). Such high costs make it extremely difficult to justify public storage in India on economic grounds, as it would be much less costly to rely on domestic private storage or on world trade and storage abroad. For that reason, the alternative policies considered here are based on providing sufficient incentives to induce the more cost-efficient private stock holders to store grains in a socially optimal way.

The fully optimal policy determines the levels of storage and trade that maximize total welfare, whereas the optimal simple rules of stabilization adjust the parameters from predetermined rules in optimizing the welfare function. These simple rules are a constant subsidy to private storage (as storage policy) and tariffs defined by an isoelastic function of border price (as trade policy). A notable result from the model is that the optimal simple rules achieve welfare gains approaching those obtained by implementing a fully optimal policy. Under simple policy rules, private storage is incentivized to exceed a storage level above the competitive level. Since private storage reacts in appropriate ways to price behavior, it combines well with the trade policy, a result that is extremely difficult to achieve with a price-band program (or its variants).

One important conclusion of the analysis is that it endorses the broad approach adopted by India of using a combination of trade and storage policies to target price stability. A second important conclusion is that, this combination of policies could be fine-tuned to significantly increase India's total welfare and significantly reduce its storage costs by adopting a more rules-based food policy. As price stabilization policies do not directly target the underlying market failures, which are often thought to be related to the economic agents' lack of capacity to cope with shocks (Gouel 2014), they are not regarded as first-best policies. Yet price stabilization policies hold considerable appeal for many policy makers who have clearly exhibited a dislike for price volatility, and certain market failures may prevent the first-best policy options from achieving their goals.

If price stabilization policies are to be used, however, it is important to identify how best to use them. In India, given the current circumstances, significant cost savings (through a combination of storage and trade costs) could be made without any significant net loss in

"pure" welfare (defined as the sum of producers or consumers surplus) through a less insulating trade policy implemented in conjunction with storage rules that are similar to, but above, competitive storage levels. These gains are predicated on efficient private sector storage, however. The current public costs of storage do not justify any level of public storage in the country without significant overall loss in welfare.

A final consideration is that this work has neglected the rest of the world's reaction to India's wheat policies, although that reaction may not be without consequence. The recent food crisis (and prior crises) demonstrated that when one country institutes trade policies to insulate from the world market, the desire of other countries to use insulating policies is reinforced, and the overall effectiveness of such policies is attenuated (Martin and Anderson 2012; Anderson, Ivanic, and Martin 2014). By definition this collective action problem cannot be solved by one country alone, but the problem may nevertheless matter for the design of an individual country's policies. If the effectiveness of trade policies is limited by partners' reactions, the implication is that storage policy may play a more important role in domestic prices stabilization than was found in this analysis.

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Annex 1: Estimation of Insulation Achieved by Current Trade Policies

To estimate the degree of insulation achieved by current trade policies, excluding trade costs (for which time-series data are not available) and assuming that at least some trade takes place between India and the RoW, equations (19)—(22) can be simplified to $P^i = \alpha P^{w\,1+\beta}$. Since these two prices are likely to be cointegrated, estimating this relationship in levels may capture their long-run dynamics; given the model's focus on dynamics around a steady state, however, the primary interest is in the short-run price transmission elasticity.

India's prices are annual producer prices from FAOSTAT,[12] converted to US dollars, and world prices are US prices of wheat as reported in the International Monetary Fund's International Financial Statistics. All prices are converted to real terms using the US consumer price index. The exchange rate and the consumer price index are from the International Financial Statistics. The sample period is from 1966 to 2008.

An augmented Dickey-Fuller test is used to test for the presence of unit root in the price series. The values of the augmented Dickey-Fuller test are presented in Table A1 for the logarithm of prices. The tests are conducted on equations with a constant (first column) and with a linear trend (second column). The null hypothesis of a unit root cannot be rejected for either of the price series. Differencing prices, the null is rejected, and prices are integrated of order 1. The long-run equilibrium relationship are then estimated; the ordinary least squares estimates are:

$$\ln P_t^i = \underset{(0.525)}{0.138} + \underset{(0.092)}{0.996^{***}} \ln P_t^w, \qquad \text{Adj-R}^2\text{: } 0.73,$$

where the numbers in parentheses are the standard errors. The augmented Dickey-Fuller tests for cointegration are reported in Table A1. The unit root null can be rejected at the 5% significance level. Thus prices are cointegrated.

Using the residuals of the long-run equilibrium equation (noted EC below), the error correction model is estimated:

$$\Delta \ln P_t^i = \underset{(0.019)}{-0.021} + \underset{(0.106)}{0.244^{**}} \Delta \ln P_t^w - \underset{(0.080)}{0.145^{*}} EC_{t-1}, \quad \text{Adj-R}^2\text{: } 0.11\text{; DW: } 2.21.$$

The speed of adjustment parameter is negative, as expected, but significant only at the 10% level. The coefficient of short-run price transmission is significant at the 5% level and indicates a short-run elasticity of 0.24, implying the coefficient of trade insulation to be –0.76.

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[12] Available at http://faostat.fao.org/, accessed March 21, 2014.

Adding lags of $\Delta \ln P^i$ and $\Delta \ln P^w$ would increase the statistical significance of the coefficients of short-run transmission and speed of adjustment but would not affect the estimated values.

Table A1: Augmented Dickey-Fuller unit root test statistics

Variable	Constant	Trend
Price		
India	-1.49 (1)	-0.73 (1)
US	-1.42 (2)	-3.15 (1)
Price differential		
India	-5.24*** (1)	-5.57*** (1)
US	-4.85*** (1)	-4.79*** (1)
Residual from cointegration equation	-3.58** (1)	-4.00* (1)

Notes: Critical values (from MacKinnon 2010) for 43 observations for testing for variable stationarity are for 10%, 5%, and 1%, respectively, -2.60, -2.93, and -3.59 with a constant, and -3.19, -3.52, and -4.19 with a trend. For testing cointegration, they are -3.14, -3.48, and -4.16 with a constant and -3.66, -4.01, and -4.71 with a trend. Number of lags in parenthesis. Lag selection is achieved according to the Akaike information criteria, considering a maximum of 3 lags. *, **, and *** indicate statistical significance at 10%, 5%, and 1% levels, respectively.

Annex 2: The optimal policy problem

To identify the optimal policy, complementarity equation (3) must be expressed as a combination of inequalities and equalities, because complementarity equations cannot be included directly as constraints in a maximization problem. A positive slack variable, ϕ, is introduced with its associated complementarity slackness conditions:

$$\phi = P_t^w + k^w - \delta E_t P_{t+1}^w, \tag{31}$$

$$S_t^w \phi = 0. \tag{32}$$

Following Marcet and Marimon (2011), the optimal policy problem under commitment can be expressed as a saddle-point functional equation problem:

$$
\begin{aligned}
J\left(A_t^i, A_t^w, \mu_{t-1}^i \epsilon_t^i, \lambda_{t-1} + \mu_{t-1}^w \epsilon_t^w\right) \\
= \min_{\Gamma_t} \max_{\Omega_t} \Bigg\{ &-d^i \frac{P_t^{i\,1+\alpha^i}}{1+\alpha^i} + P_t^i A_t^i - a^i \bar{H}_t^i - \frac{b^i \bar{H}_t^{i\,2}}{2} - (k^i + P_t^i)S_t^i - X_t^i(\theta_{i,w} + P_t^i - P_t^w) \\
&- X_t^w(\theta_{w,i} + P_t^w - P_t^i) - \frac{K}{2}(P_t^i - \bar{P}^i)^2 + \chi_t^i[A_t^i + X_t^w - D^i(P_t^i) - S_t^i - X_t^i] \\
&+ \chi_t^w[A_t^w + X_t^i - D^w(P_t^w) - S_t^w - X_t^w] + \lambda_t(\phi_t - P_t^w - k^w) + (\lambda_{t-1} + \mu_{t-1}^w)P_t^w \\
&+ \xi_t S_t^w \phi_t + \mu_{t-1}^i \epsilon_t^i P_t^i - \mu_t^i(a^i + b^i \bar{H}_t^i) - \mu_t^w(a^w + b^w \bar{H}_t^w) \\
&+ \delta E_t\left[J\left(S_t^i + \bar{H}_t^i \epsilon_{t+1}^i, S_t^w + \bar{H}_t^w \epsilon_{t+1}^w, \mu_t^i \epsilon_{t+1}^i, \lambda_t + \mu_t^w \epsilon_{t+1}^w\right)\right] \Bigg\},
\end{aligned}
\tag{33}
$$

where $\Omega_t = \{S_t^r \geq 0, P_t^r, \bar{H}_t^r, X_t^r \geq 0, \phi_t \geq 0\}$ and $\Gamma_t = \{\chi_t^r, \mu_t^r, \lambda_t, \xi_t\}$. This problem gives the following first-order conditions (after substitution of the expressions given by envelop theorem):

$$S_t^i \geq 0 \perp P_t^i + k^i + \chi_t^i - \delta E_t\left(P_{t+1}^i + \chi_{t+1}^i\right) \geq 0, \tag{34}$$

$$S_t^w \geq 0 \perp \chi_t^w - \xi_t \phi_t - \delta E_t(\chi_{t+1}^w) \geq 0, \tag{35}$$

$$\mu_t^r b^r = \delta E_t(\epsilon_{t+1}^r \chi_{t+1}^r) \tag{36}$$

$$K(P_t^i - \bar{P}^i) + \chi_t^i D^{i\,\prime}(P_t^i) = \mu_{t-1}^i \epsilon_t^i, \tag{37}$$

$$\chi_t^w D^{w\,\prime}(P_t^w) + \lambda_t - \lambda_{t-1} - X_t^i + X_t^w = \mu_{t-1}^w \epsilon_t^w, \tag{38}$$

$$X_t^r \geq 0 \perp P_t^r - P_t^s + \theta_{r,s} + \chi_t^r - \chi_t^s \geq 0 \text{ for } s \neq r, \tag{39}$$

$$A_t^r + X_t^s = D^r(P_t^r) + S_t^r + X_t^r \text{ for } s \neq r, \tag{40}$$

$$\phi = P_t^w + k^w - \delta E_t P_{t+1}^w, \tag{41}$$

$$\phi_t \geq 0 \perp -\lambda - \xi_t S_t^w \geq 0, \tag{42}$$

$$\phi_t S_t^w = 0, \tag{43}$$

$$\delta E_t(P_{t+1}^r \epsilon_{t+1}^r) = \Psi^{r\,\prime}(\bar{H}_t^r) \tag{44}$$

Annex 3: Computational details

The rational expectations storage model does not allow a closed-form solution; it must be approximated numerically. The numerical algorithm used here is based on a projection method with a collocation approach. The results were obtained using MATLAB R2013b and solved using the rational expectations solver RECS v0.6 (Gouel 2013b). Policy functions were approximated using cubic spline with 15 nodes for availability in India and in the RoW, 9 nodes for public stocks, and 7 nodes for co-state variables in the optimal policy problem. For terms with expectations, shocks were discretized using 5-point Gauss-Hermite quadratures. For further technical details, see the program code available upon request.

Two nested algorithms were used to find the parameters defining the optimal simple rules. The outer algorithm adjusts the policy parameters of the rules to maximize intertemporal social welfare given by equation (30) by applying an optimization solver. The optimization solver is the nonlinear programming solver *fmincon* available in MATLAB. Its interior-point algorithm is used along with a gradient calculated by central finite differences. For each iteration of the outer algorithm, the inner algorithm (described above) solves the rational expectations problem for the new set of policy parameters.

Two types of results are produced in the study: statistics on the asymptotic distribution and welfare results. Statistics on the asymptotic distribution are calculated over 100,000 observations from random outcomes of the stochastic variables, obtained by simulating 500 paths for 220 periods and after discarding for each path the first 20 observations as burn-in period. The random shocks are the same for all policies. The simulations are done following the approach proposed in Wright and Williams (1984): For any given value of the state variables, the approximated policy rules obtained by solving for the rational expectations are used to approximate expectations, and using these approximated expectations, the equilibrium equations are solved for the value of the response variables. This time-consuming method yields results that are much more precise than those obtained by directly using the approximated policy functions. Since all welfare terms correspond to discounted infinite sums, such as equation (25), they are calculated by transformation to a recursive formulation and value function iteration. To evaluate welfare, it is assumed that in the initial period the economy is at the deterministic steady state.

Annex 4: Effect of price stabilization on risk-averse producers

In addition to fostering food security, price stabilization policies are often justified by the need to provide stable incentives for small farmers who lack financial instruments to manage risk. In some situations of incomplete markets, risk-averse farmers would reduce their production level when facing increased revenue instability (Sandmo 1971). Because designing optimal policies in the presence of risk-averse farmers would have been particularly difficult, a simpler approach was adopted, which analyzed the consequences of the various stabilization policies on the production decisions of risk-averse farmers.

Farmers are assumed to have mean-variance preferences over their expected profit from the current harvest:

$$U\left(\Pi_{t|t+1}\right) = E_t\Pi_{t|t+1} \ -\frac{A}{2}\text{Var}_t\Pi_{t|t+1}, \tag{45}$$

where A is the coefficient of absolute risk aversion and Var_t is the conditional variance based on information available in period t. The first-order condition of the risk-averse producer's problem provides the following expression for the production level

$$\bar{H}_t^r = \frac{\delta E_t(P_{t+1}^r \epsilon_{t+1}^r) - a^r}{b^r + A\delta^2 \text{Var}_t(P_{t+1}^r \epsilon_{t+1}^r)}, \tag{46}$$

which is indeed decreasing in risk aversion and in the variance of marginal returns in farming.

The effect of various stabilization policies on production by risk-averse producers is illustrated in Table A2. This illustration is somewhat crude, as it neglects any feedback to market equilibrium from producers' behavior. For comparison, Table A2 also displays the percentage change in mean production when producers are risk neutral (from Table 3). For this illustration, the parameter of absolute risk aversion, A, is assumed equal to $4/E(\Pi)$, thus assuming a parameter of relative risk aversion equal to 4 normalized by average profits in laissez-faire.

Table A2: Effect on risk-averse producers of price stabilization policies

Variable	Laissez-faire	Trade policy	Storage policy	Both instruments
E($P\varepsilon$)	9,781	9,493	9,873	9,483
Var($P\varepsilon$)	1.56E+06	4.71E+05	9.34E+05	1.22E+05
ΔH (percentage change with respect to laissez-faire)				
Risk-neutral producers		-0.55	0.27	-0.59
Risk-averse producers		-0.22	0.42	-0.12

Accounting for risk aversion in producers' behavior changes the average effect of the policies very little, indicating that the results are dominated by the effect of mean price

change. For the policies that decrease mean production with risk-neutral producers, the sign can be reversed by increasing risk aversion and thus giving more weight to price volatility (results not displayed in Table A2).