Stocks for the stabilization of food markets Lessons from rational expectations models*

Christophe Gouel†

June 23, 2014

Abstract

This paper presents a short overview of recent research on the stabilization of food prices using rational expectations models of storage. It shows how modern tools from macroeconomics can be used to design optimal food price stabilization policies when policy makers are assumed to be concerned about food price stability. It discusses state-contingent optimal policies of storage, production and trade, but also simple stabilization rules. It argues that, despite conceptual advances in the design of stabilization policies, numerous issues remain: these policies are complex and uncertain in their incidence, they are potentially non-cooperative, and they are complex to implement because of their non-linearity and the important quantity of information required to derive them.

Keywords: commodity price stabilization, food security, storage.

JEL classification: Q17, Q18.

*Paper prepared for the FAO Expert Meeting on Stocks, Markets and Stability (FAO Rome, 30–31 January 2014). This research was generously supported by the European Union's Seventh Framework Programme FP7/2007–2011 under Grant Agreements no 290693 FOODSECURE. The author only is responsible for any omissions or deficiencies. The European Union and European Commission are not accountable for the content of the paper.

†INRA, Économie Publique, and CEPII (christophe.gouel@grignon.inra.fr)

1 Introduction

Can food price stability and welfare improvements be achieved with storage policies? Since the 2007–08 food crisis, this issue is at the forefront of food policy debates (HLPE, 2011, World Bank, 2012). Although there is huge controversy in the economic literature related to the effectiveness of past and current storage policies, national policy makers seem to consider them important instruments to achieve food security in their countries. In 2007–08, out of 81 developing countries surveyed, Demeke et al. (2009) found that 35 released stocks at subsidized prices. The importance of stocks for policy makers is well illustrated also by the fact that this issue threatened the conclusion of the 9$^{\text{th}}$ WTO Ministerial Conference in December 2013 (Häberli, 2014). Hence, it is important to understand what we can expect from well-designed storage policies and how they can best be designed.

This paper addresses these questions through an overview of recent research on optimal food price stabilization policies which was started with my PhD research (Gouel, 2011, 2013b,a, Gouel and Jean, forthcoming, Gouel et al., 2014). It proposes a framework that allows optimal storage policies to be designed and studied and summarizes the results of optimal policies in various settings.

The proposed approach to designing an optimal policy is inspired by the modern macroeconomics literature. The new synthesis in macroeconomics (Woodford, 2009), which is built around the neoclassical stochastic growth model, recognizes the need to study agents' interactions based on their microeconomic behavior, and acknowledges the importance of consistent intertemporal decisions and endogeneity of expectations. In this setting, public policies, especially monetary policies, have been shown to be effective for improving welfare since the macroeconomic dynamics is affected by several market imperfections, such as price or wage rigidities. The canonical model for studying commodity price behavior and stabilization policies, that is, the rational expectations storage model, encompasses several of these features (Wright, 2001). It represents price dynamics as stemming from the behavior of optimizing agents endowed with rational expectations. Productivity shocks are the primary source of dynamics, and these shocks are smoothed by private storage, which follows an intertemporal arbitrage equation. This simple setting is sufficient to explain most features of price dynamics (Cafiero et al., 2011). Thus, the literature on the storage model was already consistent with most of the principles on which the new neoclassical synthesis relies, except that it is used to analyze exogenously given, not optimal policies.

The value added of the approach in this paper is its use of the framework provided by the rational expectations storage model to study the design of optimal price stabilization policies. In a context where there is a social preference for food price stability, which can be based on micro-foundations or not, it shows how these policies can be designed and what are their properties. To design optimal policies, a motivation for food price stabilization is introduced in the social welfare function, and storage policies are determined by maximizing the resulting objective. In line with the macroeconomics literature, different kinds of policies are distinguished: optimal policies under commitment, under discretion, and optimal simple rules. The overall approach relies on modern mathematical and computational tools for the study of dynamic economics, but the corresponding technical requirements can occasionally obscure the underlying simple economic mechanisms, so this paper attempts to summarize the approach and the results while abstracting from the technical details.

The rest of the paper is organized as follows. Section 2 summarizes the literature on food price stabilization policies. Section 3 presents the methodological approach used to design and study optimal stabilization policies. Section 4 presents the results for state-contingent optimal policies: rules of intervention that are contingent on the state of the system, so are very flexible but also potentially very complex. These policies are important to assess the best policy options, but may be difficult to implement; thus, Section 5 discusses the design of simple intervention rules. Both state-contingent and simple rules are designed to increase social welfare but in doing so they may generate large redistributive welfare effects among agents. The incidence of these policies is discussed in Section 6. Section 7 concludes.

2 Related literature

While the approach described in this paper relies on modern tools and is an innovation with respect to the previous literature, the determination of welfare-enhancing storage rules is not new and has been the object of much research and various approaches (see Labys for an early survey, 1980, and Wright, 2001 for a more recent one). These various approaches are briefly described in what follows.

Dynamic programming Modern studies of storage rules began with Gustafson (1958), who proposed a dynamic programming solution to the rational expectations storage model. He used dynamic programming to maximize the intertemporal sum of social surplus, thus the solution to this problem is an optimal storage rule. However, Gustafson (1958) recognizes that, although optimal, this storage rule is the same as would be achieved by private storers maximizing their expected profit, a result stemming from the absence of market imperfection.

Gustafson's approach prevailed up to the early 1980s when it was extended by several studies that derived optimal storage policies through dynamic programming (Gardner, 1979a,b, Kennedy, 1979, Knapp, 1982). Gardner (1979a) extends Gustafson's method to account for elastic supply, and proposes an optimal storage rule in situations where high prices entail external costs. Knapp (1982) considers optimal storage when trade is possible. However, the dynamic programming approach has some limitations: it is impossible to solve for the decentralized equilibrium of a model with market imperfections, since this situation is not amenable to a maximization problem; and when introducing imperfections, as in Gardner (1979b), the optimal policy is the solution to a benevolent planner problem, not to a policy maker maximizing social welfare while accounting for the constraints created by private agents' behavior and market equilibrium.

Exogenous storage rules With the development of new numerical methods, the analysis shifted in the 1980s from the study of optimal storage rules to the study of a decentralized system in which speculative storers play a central role (Wright and Williams, 1982a, 1984). Finding optimal policies subject to this equilibrium behavior is difficult, and with the exception of Wright and Williams (1982b) and Williams and Wright (1991, Ch. 15), was not addressed at this time. Most studies introduce exogenous storage rules and assess their incidence (Miranda and Helmberger, 1988, Wright and Williams, 1988, Gardner and López, 1996, Srinivasan and Jha, 2001). Because these studies do not introduce market imperfection or a social preference for price stability, the optimal situation is always the situation without intervention. The analysis of exogenous storage rules in this setting allows for the identification of their effects on the market, but says little about what would be the optimal action were public intervention useful.

Marshallian analysis Before the developments of the rational expectations storage model in the 1980s, most work on the welfare effects of stabilization used the Waugh-Oi-Massell framework, a surplus analysis in a simple demand/supply market model. This work focused more on the benefits that could be expected from complete price stabilization, than on the precise rules for achieving it. Drawing on the work of Waugh (1944) and Oi (1961), Massell (1969) shows that price stabilization is likely to increase total welfare. This approach has been extended in various directions. For example, Turnovsky (1974) shows that higher welfare gains can be expected if producers have to plan their production before realization of uncertainty since stabilization allows more efficient allocation of resources. Turnovsky (1976) considers a situation with multiplicative rather than additive disturbances and shows that this assumption can reverse the results. Edwards and Hallwood (1980) introduce the cost of buffer stock schemes and determine the optimal degree of price stabilization. Nevertheless, none of these improvements is able to correct for the principal problem in this approach: the absence of private storage. Assessing the effect of public storage policies while neglecting private storage is equivalent to saying that government has at its disposal a technology (storage) that is not available to private agents. Therefore, it is not surprising that public stabilization of markets is shown to improve welfare since the benchmark does not account for the already stabilizing role of private actions.

Econometric policy evaluation This approach builds on the macroeconometrics literature before the rational expectations revolution. It estimates structural econometric models and uses the results to simulate stabilization policies. The simplest models are supply-demand models, which consist of four equations: demand, supply, price and market equilibrium (see Labys, 2006, Ch. 1, for a survey). Supply is determined as a function of lagged prices, and price is a function of inventories. This simple framework has been extended to include many commodities and many countries in one model.

One of the first applications of this method is Desai (1966), who estimates a model of the world tin market and uses it to test alternative stockpiling policies. Ghosh et al. (1982, 1984, 1985, 1987) and Hughes Hallett (1984, 1986), analyzing the copper market, propose the determination of optimal stabilization policies by minimizing a quadratic objective function, representing the squared deviation of endogenous variables from a target trend, subject to the equations estimated in the econometric model. These studies compare the optimal solution to simple rules of stabilization. This literature led to optimism with regard to the possibility of stabilizing commodity markets. However, the approach is subject to the same criticisms as the macroeconometrics literature that inspired it (see Miranda and Helmberger, 1988, Salant, 1983, for critiques of this approach), particularly the Lucas (1976) critique. Policy recommendations based on reduced-form relationships estimated on historical data can be misleading because the model parameters are not structural and would change with the policy. In addition, without any micro-foundations, the objective of the maximization problem cannot be grounded on welfare theory,[1] which could make the interpretation of optimal policies difficult.[2]

3 Overall approach

The overall approach adopted here takes its inspiration from the design of optimal policies in macroeconomics. Government chooses the policy rules (e.g., rules of public storage, subsidy to storage, trade policies) that maximize a welfare objective while taking into account the constraints implied by private agents' behavior and market equilibrium.

The constraints are the equations defining market equilibrium and agents' reaction functions to any intervention. They are given by the rational expectations storage model used to represent the studied market. The rational expectations storage model is a simple demand/supply model to which a few dynamic features have been added. Supply level is decided one period before its effective realization and is subject to a random shock. So, to make their decisions, producers need to form expectations about prices and yield. In the short-run, supply is inelastic. Market equilibrium is achieved by adjustments to demand and to stock levels. Stocks are managed by competitive and risk neutral agents that make storage decisions which depend on the

[1] However, Hughes Hallett (1984) justifies a quadratic social objective as approximating the risk aversion of private agents.

[2] In a series of IFPRI papers, a similar approach has been applied to grain storage management (Krishna and Chhibber, 1983, Pinckney, 1989, Goletti et al., 1991).

spread between the current price and the price expected at the next period. For a detailed description of the storage model and its equations, see Williams and Wright (1991).

Government maximizes at some date s an intertemporal objective function:

$$\max \mathrm{E}_s \sum_{t=s}^{\infty} \beta^{t-s} \left[W_t - \lambda \left(P_t - P^* \right)^2 \right], \tag{1}$$

where E_s is the expectations operator conditional on information available at time s, β is the discount factor, W_t is a standard utilitarian social welfare function (i.e., the sum of the surpluses including the fiscal costs of the policies), P^* is a target price level around which government wants prices, P_t, to be stabilized (in practice, the deterministic steady-state price[3] will be used as a target), and $\lambda \geq 0$ measures the importance assigned to price stabilization in total welfare.

Why is the quadratic price term needed in the objective function? If food price stability is valuable in itself, should it not already be part of a standard utilitarian welfare function? Under standard assumptions, the equilibrium of a competitive storage model is an optimum: it is the same as the solution to a market surplus maximization problem (Scheinkman and Schechtman, 1983). If no market imperfections are included in the model, the level of price stability achieved is already optimal with respect to an objective equal to the sum of the surpluses. To justify a storage level above the competitive level, which seems to be a policy makers' objective in countries with large poor populations, it is necessary to go beyond this simple objective. This is the role of the quadratic price term.

Using a quadratic price term was standard in the early literature on econometric policy evaluation, mentioned previously, and it is also standard in macroeconomics to use quadratic loss functions as objectives in the design of monetary and fiscal policy (Woodford, 2010). In our case, it is a simple way to capture the cost of food price volatility. Although the quadratic term is a means of introducing, in a tractable way, additional concavity in the social welfare function, it can be endowed with some micro-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 et al. (1980), λ would in this case be equal to $\gamma (R - \nu) D(P^*) / (2P^*)$, where $D(P^*)$ is demand at the steady-state price, and γ, R and ν, respectively, are values at the steady state of the commodity budget share, risk aversion relative to income risk, and income elasticity. λ will be positive if risk aversion is higher than income elasticity, which seems reasonable for staple food products. Thus, the objective function with the quadratic price term would represent an approximation of social welfare for an incomplete-market economy in which risk-averse consumers cannot insure against food price risk.[4]

It is not the aim of this paper to discuss all possible market imperfections that could justify public interventions and the inclusion of a quadratic term in the social welfare function (see Gouel, 2014, for more). However, it is important to note that most market failures considered in the literature are related to the difficulties agents face in coping with shocks, not to the volatility of prices *per se*. Since price stabilization policies do not target the underlying problem, they are usually considered second-best policies. Yet price stabilization policies hold considerable appeal for many policy makers, and certain market failures may prevent first-best policy options from achieving their goals.

The welfare objective (1) is maximized while accounting for the constraints implied by private agents' behavior in the market. These constraints are given by the canonical storage model (Wright and Williams,

[3] The deterministic steady-state price is the price in the absence of shocks and not expecting future shocks.

[4] In the papers Gouel (2011, 2013a,b), and Gouel and Jean (forthcoming), the objectives used to design optimal storage policies are not (1) but micro-founded welfare functions corresponding to a situation with risk-averse consumers and incomplete markets. However, the same policies could be obtained using the simpler quadratic objective proposed here.

1982a) or storage-trade models (Williams and Wright, 1991, Ch. 9), when extended to an open-economy situation. There is no closed-form solution to rational expectations models of storage; they must be solved numerically. So all the results summarized below are derived from numerical simulations and consequently are contingent on the assumed calibrations. The models have been calibrated on values typical of cereal markets in developing countries. Various settings have been considered: closed and open economies, with inelastic and elastic supply, and for small and large countries. Overall the results prove very robust to the calibration, and any difference following changes in some parameters can be easily explained.

Storage models are stochastic problems. Their solution describes the reaction of storage, price, trade, and other response variables to changes in the state of the system. The state of the system depends on the model features, but generally includes availability in each country (i.e., the sum of production and starting private stocks), and in the case of public stockholding starting public stocks can also be a state variable. As a consequence, the solution to an optimal policy problem is not a target optimal storage level that the government should aim for, but a state-contingent storage rule prescribing how stocks should be adjusted to any change in economic conditions.

4 State-contingent policies

4.1 Competitive storage rule

Before addressing the issue of optimal storage policies, it is important to understand the model's behavior at the benchmark, in *laissez-faire*. If there is no weight given to price stability in social welfare, $\lambda = 0$, the optimal solution to program (1) in closed economy is the same as the market equilibrium (Scheinkman and Schechtman, 1983), and the optimal storage rule is the competitive storage rule. This competitive storage rule and the equilibrium under *laissez-faire* have the following properties.

Private storers face several costs. The costs usually considered are those related to physical storage, deterioration of the stored food or loss of quality after some time in storage, and the opportunity cost of the money that has to be spent to purchase the food and pay for the storage costs. Storers can cover their costs only by buying low and selling sufficiently high. When the market price is so high that these costs cannot be expected to be covered, private storers dispose of all their stocks or abstain from buying stocks, and do not store anything for the next period. On the other hand, when market price is sufficiently low that the next-period expected price exceeds all storage costs, storers stockpile. Their collective accumulation tends to raise the price up to the point where the price of the last unit stored is equal in expectation to the next-period price minus storage costs. This behavior of private storers arbitrates all intertemporal profit opportunities.

Because of this stockpiling behavior, prices have a regime-switching behavior: for positive and sufficient stocks a supply shock (δ in Figure 1) has a moderate effect on prices because the shock is mostly absorbed by stock adjustments; without stocks the same supply shock has a much larger effect on prices because the adjustment comes from consumers' demand, which is likely to be quite steep for staple food products.

These two regimes are displayed also in the storage rule (Figure 2, black solid curve). Corresponding to the threshold price above which it is no longer economic to hold stocks, there is a threshold availability: the availability in the market below which prices are too high for stocks to be held. The precise location of these thresholds depends on the specifics of the model (demand and supply elasticities, curvature of the demand function, storage costs, ...), but usually is not far (above or below) the deterministic steady state of the model (Wright and Williams, 1982a, Table 1). For availability above the threshold, stocks are positive and increase with availability. A part of the availability in excess of the threshold is stockpiled. The marginal propensity to store tends to increase with availability and is always strictly below 1.

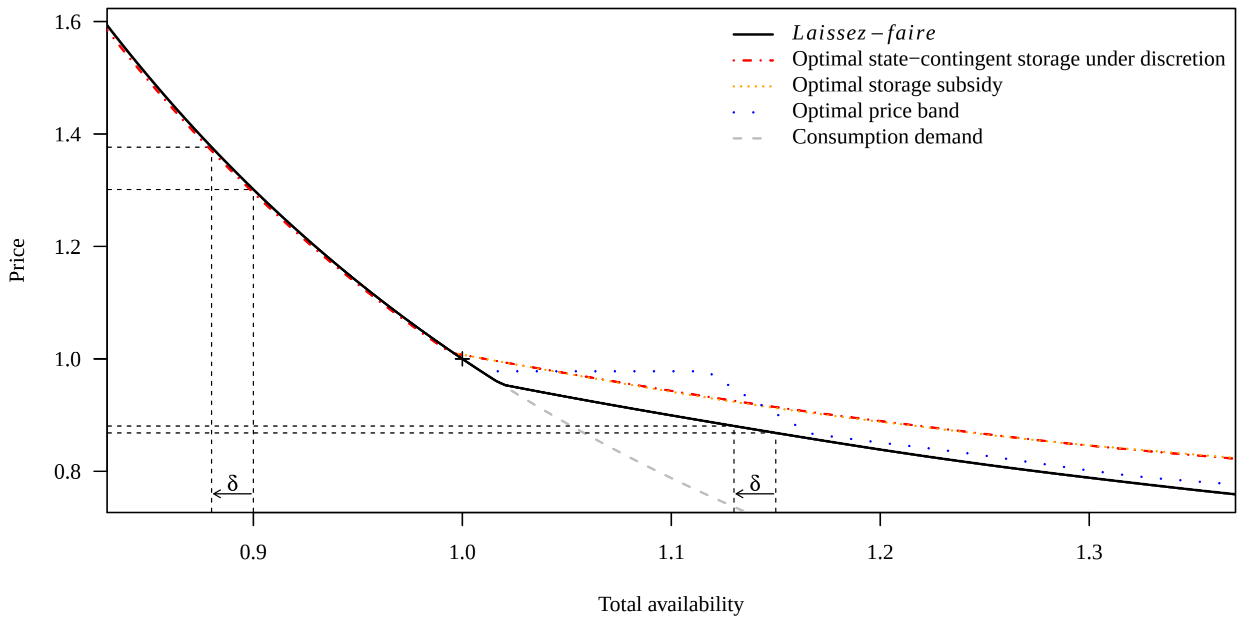

Figure 1. Price as a function of availability for various schemes of public intervention. Policy rules obtained for a closed-economy storage model with isoelastic demand function and isoelastic marginal production cost with the following calibration: demand elasticity -0.4, supply elasticity 0.5, storage cost 6% of steady-state price, discount factor 0.95, and steady-state price and availability equal to 1. The steady state is indicated by a $+$ (Source of the results: Gouel, 2013b).

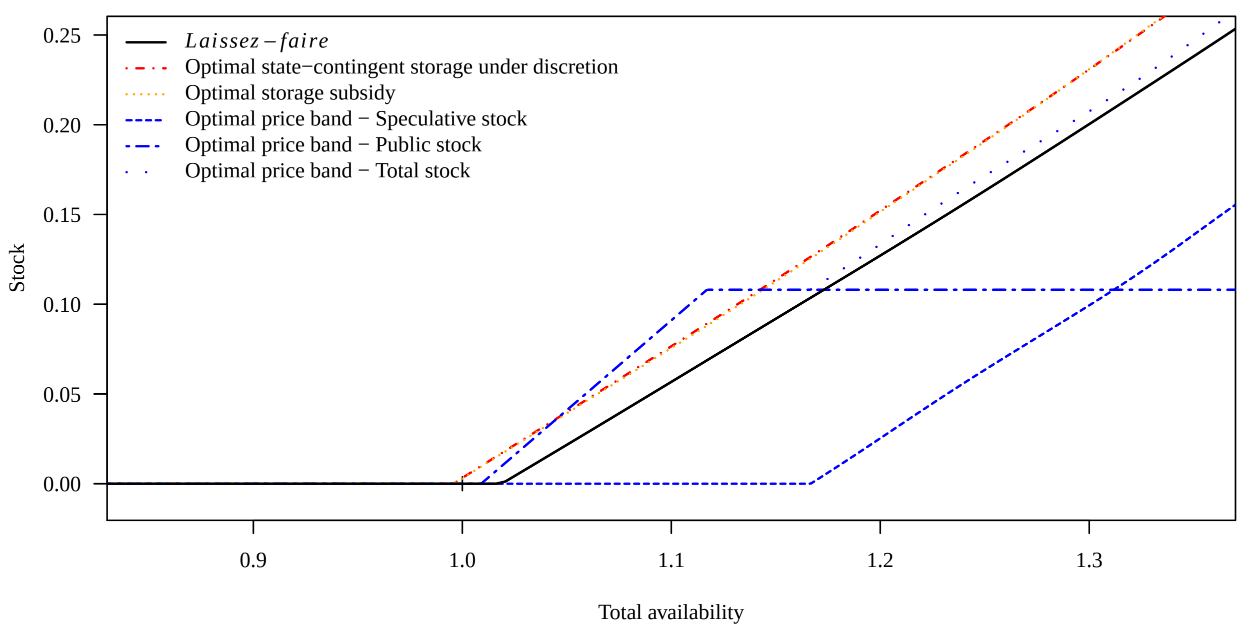

Figure 2. Storage rule for various schemes of public intervention. Same calibration and source as Figure 1.

These properties of competitive storage rules are important to understand the effects of storage policies, because as long as private storers are authorized to operate along public storage their behavior has to be accounted for in the design of the policy. For example, recognizing that risk-neutral private storers exhaust all intertemporal profit opportunities implies that there should not be profit opportunities available for public storage if it is as costly as private storage. Even a well-designed storage policy, aimed at buying low and selling high while providing more stabilization than private storage, should not be expected to cover its costs. This does not reduce the potential for storage policy to increase welfare but it should not be assumed from the start that a public storage policy will result in break-even because storers buy low and sell high. This may occur – and possibly over several years – but by design, public storage policy must be costly in order to exceed what is being done by private arbitrageurs. Since private storers operate on average at zero profit, additional stockpiling can only lead to storage at a loss. Any insistence on covering costs may lead to delayed stock releases and a less efficient storage rule.

4.2 Optimal storage policies

If there is a social preference for price stability (i.e., $\lambda > 0$), competitive storage does not maximize welfare. The social preference for price stability would dictate more price stability than that achieved by a competitive market equilibrium, and thus stock levels higher than competitive levels. How can stock levels be increased beyond competitive levels? With state-contingent rules, this can be achieved either by providing appropriate incentives to private storers via a state-contingent subsidy proportional to the level of stocks or directly by accumulating and releasing public stocks. If public storage costs are the same as private storage costs, the two approaches are equivalents.

What are the differences between a competitive storage rule and an optimal rule? The storage rules are qualitatively very similar but an optimal storage rule prescribes higher storage levels (Figure 2, red dash-dotted curve). Under optimal storage, the availability threshold is lower, so stocks are accumulated for lower levels of availability. For positive stocks, the marginal propensity to store is always higher than under the competitive rule. Since optimal storage is always superior to competitive storage, it actually reduces the expected price spread between two consecutive periods such that there are no profit opportunities left for private storers. There is a complete crowding out of speculative storers under an optimal public storage policy. Since the threshold level is lower, stocks are accumulated for lower levels of availability: the increased stock accumulation for a given level of availability means that storage tends to reduce the occurrence of low prices. The subsequent sale of stocks will also prevent the occurrence of high prices, but only to the extent that stocks are available. So it tends to skew the price distribution more – creating an effective lower bound on prices, and decreasing high prices but less completely.

An optimal storage rule is very similar to a competitive storage rule because both operate according to the same logic. A private storage rule arbitrates prices intertemporally, while an optimal storage rule arbitrates the social marginal value of food. The social marginal value is the sum of the private marginal value (i.e., price) and the marginal value of price stability, which is proportional to $\lambda \left(P_t - P^*\right)/2$.[5] The dynamics of the social marginal value of food reinforces the incentives to store with respect to the price dynamics only. Incentives are higher to exploit low prices to stockpile, because if prices are below their target, the social marginal value is below the private marginal value. Conversely, the incentives to sell at high prices are higher, because the social marginal value is higher than the private marginal value. Private storers do not account for the high social costs of the deviation of prices from the target, and so they provide insufficient stabilization.

The complete crowding out of private storage is a consequence of the similarities of the storage rules. Since the optimal storage rule is always superior to or equal to the competitive rule, it does not leave any profit opportunities for arbitrageurs to sustain their activity. There are reasons to expect incomplete crowding

[5] See Gouel (2013a) for an analysis of the first-order conditions of the optimal policy problem.

out. This will be the case if private storage is motivated not just by speculation, or if it shows some structural differences from public storage, that is, if there are some qualitative differences between the storage rules. Wright and Williams (1982b) and Williams and Wright (1991, Ch. 15) touch on this by analyzing the management of strategic petroleum reserves. Two features explain the coexistence of both public and private stocks: in the first study, private storers are assumed to receive a convenience yield from the holding of stocks, implying that they hold stock even if the apparent return is negative; in the second study, they suppose that public stock is not held at the same location as private stock – for example, private stocks may be located closer to the market – so that private storers face a different price instability, which may sustain their activity. For these reasons, and because private storers hold stocks to smooth the natural seasonality of agriculture production, it is reasonable to think that, in practice, an optimal public storage policy would not completely crowd out private storage. But there will be very little scope for private storage to obey a speculative motive in the presence of welfare-maximizing public storage.

4.3 Commitment versus discretion

In related fields, and especially in monetary macroeconomics, a major preoccupation when designing dynamic policies has been the analysis of the "time consistency" of the policies, that is, the policy maker's incentives to deviate from the optimal policy after private sector agents have made irreversible decisions based on expectations that the policy maker will stick to its policy rule. This could be an important issue also for storage policies given policy makers' history of lack of commitment to food security policies (Tschirley and Jayne, 2010).

The potential source of time inconsistency in storage policies arises mostly from the interplay between storage and production decisions. Producers make their decision accounting not only for the current public storage decision which impacts current and future prices but also for future public storage since this will impact the future prices at which production will be sold. A storage policy may be time inconsistent if it is in the interest of the policy maker to deviate from the announced storage rule once producers have made their decisions for the next period. More generally, the time inconsistency concerns all dynamic decisions that may react to the storage policy: domestic and foreign private storage, investment in processing plants, etc.

With respect to time consistency, two kinds of optimal dynamic policies are usually distinguished: policies under commitment and discretionary policies. The policies under commitment are designed assuming that policy makers maximize intertemporal welfare at an initial date and apply the resulting policy rules to all subsequent periods. Such policy requires commitment from policy makers because were they to optimize welfare at a subsequent period the resulting policy would likely be different from the initial one. Discretionary policies also are designed by maximization of intertemporal welfare but account for the fact that policy makers systematically will reoptimize at subsequent periods.

What are the differences between these policies? Since a policy under commitment is decided at some initial date, and not reoptimized at each period, the policy rules will be history-dependent. They will depend on the histories of all the state variables after the initial period.[6] Committing to optimal policy rules at some initial date gives policy makers some influence on private sector agents' expectations, which will help to achieve price stabilization. In a closed-economy context with elastic supply, the path-dependence of an optimal storage policy under commitment works as follows (Gouel, 2011, Ch. 5). In this case, public storage is a function not only of current availability but also of previous availability. When current availability is low, it is difficult to stockpile without hurting consumers by raising prices too much. However, to ensure

[6] Formally, this path-dependency is expressed by adding new state variables to the problem. These new state variables are lagged Lagrange multipliers corresponding to constraints with forward looking variables in the maximization program of the policy makers (Marcet and Marimon, 2011). These lagged Lagrange multipliers summarize the history of the natural state variables.

sufficient availability in the future, government promises producers a high price at the next period, thus creating incentives for high production levels. At the next-period, the only way for government to meet its commitments is to stockpile more in order to raise the price for producers. Conversely, when availability is high, government prefers to decrease production more than producers would tend to do so, to avoid further stock accumulation. It thus promises a lower price at the next period and, in order to keep this promise, it has to stockpile less than it would have done without commitment, in order to force the price down.

So the additional price stability achieved by an optimal storage policy under commitment stems from making production decisions more elastic. The mechanism of this policy points to the fact that storage is not the only instrument that can be used to stabilize prices, it is also possible to improve price stability by incentivizing producers. However, if the production instrument is not used (see next section on production policies to complement a storage policy), under commitment government attempts to control production in addition to storage. The limit of this policy under commitment is that adherence to this rule is complex, and by being time inconsistent, it creates incentives to deviate from the rule.

In contrast, an optimal discretionary policy is not history-dependent. It is a policy rule that is a function only of natural state variables – availability in previous example – making it a much simpler rule, and as shown in Figure 2, one that is very similar to a competitive storage rule. In Gouel (2011, Ch. 5), the discretionary policy achieves 92% of the gains achieved by the policy under commitment. The fact that gains from commitment are so limited with respect to an optimal policy under discretion may be related to the specifics of this model. However, since the scope for making production much more elastic is probably quite limited, and there are no other evident dynamic decisions to manipulate, we can conclude tentatively that in the context of optimal storage policies, there may be few gains from the ability to commit to a state-contingent policy rule.

4.4 Complementary optimal production policy

Even in a closed economy, stocks are not the only instrument to stabilize prices. It is also possible to use a countercyclical production policy to complement a storage policy. As mentioned in the previous section, incentives to produce can be manipulated through a time-varying storage policy, but it is more efficient to use a separated and dedicated instrument, such as a subsidy/tax to production.

At first glance, policies related production may seem less useful for alleviating food price spikes since, unlike stock which can be released when price rise, production cannot be increased immediately. The interest of a production policy is to complement storage policy. Storage has limits as a stabilization instrument. If it is optimal in a period of scarcity to dispose of all stocks, the following period will be extremely risky since supply will depend completely on the future production shock. The opposite situation of glut also creates problems. Following a succession of good production shocks, large stocks will be accumulated to prevent prices from decreasing too far. These large stocks will be very costly to carry. These two situations can be partially alleviated by an optimal production policy that would consist of incentivizing producers to reduce production when stocks are plentiful, and to increase production when stocks are depleted. Producers naturally reduce production when stocks are plentiful and increase it when they are exhausted. But they do it so as to equate their marginal costs with their expected marginal benefits, which are based on prices, not on the social marginal value of food. Production is not decreased enough when stocks are plentiful, and is not increased enough when stocks are low. So an optimal production policy consists of making production more elastic (Gouel, 2013a).

It is a relatively common practice for storage policies to be complemented with production policies. The precise instruments differ depending on the situation. For example, these types of policies were common in the US as part of supply management, until the 1996 FAIR Act (Gardner, 2002, Ch. 7). The US Secretary of

Agriculture decided on the percentage of land that farmers should set aside each year in order to qualify for the price support program. In another context, Demeke et al. (2009) surveyed the policy response to soaring food prices in 81 countries, and note that during the 2007–08 food crisis many of them supported production to ensure a sufficient supply.

A state-contingent production policy makes sense only for a storable commodity. Without storage, the rational expectation solution to the model without public intervention is a constant planned production level (Muth, 1961). Storage creates variation in the expected price, and therefore justifies the variation in production with growers producing more when availability is expected to be low. An optimal subsidy/tax magnifies this effect beyond private behavior. In essence, this instrument plays a complementary role to storage.

4.5 Storage in an open-economy setting

Except for analyzing international commodity agreements in which the world market could be seen as one large autarkic country, most policy questions regarding storage concern open economies, and so the interaction between trade and storage. However, most results relating to storage policies, whether considering exogenous or optimal policies, derive from closed-economy settings. There are few results obtained in an open-economy setting, and those few are likely to be very contingent on the framework considered, because storage policies in an open economy depend on the trade status of the country – importer, exporter or self-sufficient – and on the size of the country under consideration – large and small economies will not have the same optimal mix of storage and trade policies. These difficulties are compounded by the fact that storage rules in an open economy present more nonlinearity than in closed economies because of their interaction with trade, which may also present a regime-switching behavior.

A first remark is in order. It is generally not true in an open-economy setting that if $\lambda = 0$ the optimal solution is the same as the market equilibrium outcome. If the country is not small, if it has some market power over the world market, then the optimal solution will be one in which storage and trade policies are used to manipulate terms-of-trade. Since this has little to do with the price stabilization objective, let us first concentrate on the case of a small country as analyzed in Gouel and Jean (forthcoming).

Gouel and Jean (forthcoming) analyze the case of a small, normally self-sufficient country, where supply is inelastic. The country takes the world price as given, and world price is generated by a standard competitive storage model. This situation of a country that is self-sufficient at steady state, but with a price oscillating between export and import parity prices depending on domestic and foreign shocks is ideal for studying the trade-offs between storage and trade policies, since the economy under study is not continually connected to the world market. In this setting, Gouel and Jean (forthcoming) find that the implications of increasing domestic price stability through storage or through trade policy are very different. Storage policy on its own is not effective at preventing high prices because periods of price spikes occur when a country is very likely to be connected to the world market, through exports or imports. Storage could prevent spikes from domestic scarcity but stock release would need to be sufficiently high to completely crowd out imports, and holding sufficient stocks so as to displace imports could be a very costly policy. On the other hand, storage policy alleviates low prices by increasing stock accumulation and so leads to asymmetric price stabilization by reducing the occurrence of low more than high prices, which increases the mean price. In a closed economy, storage is known to skew the price distribution: because of stockouts, storage is better at alleviating low rather than high prices. In an open economy, the capacity to prevent high prices is further limited by the possibility of trade. During price spikes, a normally self-sufficient country is often connected to the world market either as an exporter if the scarcity originates in the rest of the world, or as an importer if it originates in the domestic economy. These connections to the world market will make storage releases much less efficient at decreasing domestic price than in autarky since they have to stabilize the world market not just the domestic market. This means that, in the absence of a flanking trade policy (i.e., export restrictions), a storage policy in an open economy stabilizes prices by preventing the occurrence of low prices, but not much price spikes, so it increases the mean price. The additional storage has consequences also for trade. The increased stock levels reduce imports and increase exports.

In Gouel and Jean's setting, where trade costs are double the storage costs, a countercyclical trade policy is much more efficient than a storage policy to stabilize prices. In particular, it reduces the occurrence of high prices by using export restrictions and import subsidies. Because trade policy reduces price volatility and the occurrence of price spikes, it reduces the incentives of private storers, and storage would decrease by 20% in trade policy only simulations. Stabilization is more efficiently achieved by combining trade and storage policies since trade policy limits the "leakage" of storage policy to the world market and is efficient in preventing high prices, while storage is better at preventing low prices. Export restrictions are an essential component of this policy: not using them hugely reduces the potential gains and allows more of the effect of world price spikes to be transmitted to the market.

In the different context of a large country, with a model calibrated on India's wheat market, Gouel et al. (2014) show that storage policy alone is able to stabilize prices without raising the domestic price too much thanks to the breadth of the trade parity prices, but trade policy alone is nonetheless much more efficient at stabilizing prices. The exact trade-off between trade and storage policies is still an open research question and will depend on the specifics of each situation, but the following insights should apply. The effectiveness of a storage policy should be all the more important if the country concerned is large and its trade parity prices are widely spread: storage policies are effective if their effect does not leak to the world market, they make sense if the country spends enough time between parity prices.

The important role of trade policy in any policy of stabilization of domestic food prices should trigger a warning about their eventual effectiveness. When countries adjust their trade barriers to satisfy domestic objectives, they also affect the terms-of-trade of their trade partners, which may as well modify their trade policies in reaction. The Nash equilibrium resulting from trade retaliations may eventually decrease collective welfare.

5 Optimal simple rules

Fully optimal policies, as described above, provide an understanding of the best policy options and upper bounds to the welfare gains that can be achieved by stabilization policies. However, they have drawbacks that limit their consideration in applied policy discussions. They are complex. They provide optimal levels of storage or trade policies corresponding to the current state of the market. However, these optimal levels are nonlinear functions of the state and these functions may not be easily explained to the private agents that will have to operate in such a policy environment, or the functions may not be robust to changes in the model setting. In addition, under commitment, optimal policy rules depend not only on the current states of the system but also on its past states through the presence in first-order conditions of lagged Lagrange multipliers. These Lagrange multipliers are model-dependent and not observable, and so would prevent implementation of such policies.

To discuss policies that can actually be implemented, it might be better to rely instead on simple rules of intervention: rules of public behavior providing a simple feedback between observable variables and policy instruments. An obvious example of such simple rules is a price-band program in which public stocks are accumulated to defend a floor price, and released to prevent the price from exceeding a ceiling price. Here, the trigger variable is price. Price is usually easier to observe than availability, which is key to state-contingent policies. Simple rules can be designated as optimal simple rules if the parameters that define their behavior (e.g., the bounds in a price band) are chosen optimally to maximize social welfare.

By definition, since they are not fully flexible with respect to the state of the market, optimal simple rules do not provide an optimal policy for each situation. However, reliance on them presents many advantages, which are extensively documented in a different context in the monetary and fiscal policy literature (Schmitt-Grohé and Uribe, 2007, Taylor and Williams, 2010). Being rules-based, optimal simple rules entail commitment from policy makers. Once the rules and their parameters have been decided, it is possible to delegate the management of stocks to an independent organization, which will avoid discretionary public interventions. Simple rules will make the policy environment more predictable for private agents, setting the stage for a long-run transition to a more market-based environment. Lastly, they can be expected to be more robust to model uncertainties than fully optimal rules that require complete knowledge of the economy.

In what follows, two simple rules commonly encountered in the literature are discussed: a subsidy to storage and a price-band program.

5.1 The performance of a storage subsidy

A constant subsidy to private storage is an extremely simple rule. It is defined by just one parameter, the level of subsidy, and it is constant, there is no feedback from observables. A notable result is that an optimal subsidy to private storage can achieve most of the welfare gains achievable by a fully optimal policy. In a closed-economy context, Gouel (2011, Ch. 5) shows that the welfare gains from a constant subsidy to private storage represent 93% of the gains achieved under commitment and are almost equal to the gains from an optimal policy under discretion. This closeness of the welfare gains between an optimal subsidy and an optimal discretionary policy holds for various demand and supply elasticities, and various weights on price volatility.

The capacity of a storage subsidy to achieve high levels of welfare gains relies on the idea that private storers are good at reacting to evolving economic situations but may provide too little stabilization in the absence of a subsidy. With an appropriate but simple incentive they follow a similar storage rule to what a benevolent planner would adopt. This behavior is consistent with Figure 2, where the storage rules for an optimal storage subsidy (orange dotted curve) and an optimal state-contingent storage policy are almost identical.

In an open-economy context, the subsidy policy has to be complemented by a trade policy. With a model calibrated on India's wheat market, Gouel et al. (2014) propose a storage subsidy to accompany a trade policy where the power of the tariff (1 plus the tariff) varies as an isoelastic function of the border price. In this case, there is an additional parameter to optimize: the elasticity of price transmitted from world price. This combination of simple rules in this context achieves 86% of the gains achieved by the optimal policy under commitment. Given that fully optimal policies in open economy are highly nonlinear and may pursue an objective of terms-of-trade manipulation in addition to the price stabilization goal, the good performance of a simple storage subsidy is an important result.

5.2 Price bands as optimal simple rules

To analyze optimal price bands, a general class of price-band schemes with three parameters is considered. The three parameters are the floor price, the ceiling price, and a capacity limit on public stock. Such a price band behaves like a standard price band except that when public stocks reach their capacity limit the accumulation ceases and the floor price is no longer defended. The capacity limit on public stock prevents excessive or explosive stock accumulations that can arise from inadequate combinations of floor and ceiling prices. Since the parameters are determined optimally to maximize social welfare, if the capacity constraint is not useful to improve welfare, it will be given a very high value thereby making it redundant. So there is no loss of generality in considering a price band with a stock capacity constraint.

When designed optimally, price bands can achieve good welfare results, although smaller than a storage subsidy. In the closed-economy example represented in Figure 2, the price band achieves 74% of the gains achieved by the optimal policy under discretion. As in the case of a storage subsidy, the reasonably good performance of a price-band program is explained by its capacity to increase stock levels close to the optimal levels. In Figure 2 (blue curves), for an availability close to steady state, levels of total stocks are increased with respect to competitive levels by public stockpiling resulting from accumulation at the floor price. In this situation, stock levels increases more with availability than with all other storage schemes because the floor price compels the government to buy all the quantities proposed when the market price is at the floor price. So the marginal propensity to store out of availability is equal to 1, but is always inferior to 1 with other schemes.

The price band disincentivizes private storage but not completely, and its presence even allows total stock levels to exceed their competitive levels. When public stocks reach their capacity limit, an increase in availability does not lead to any additional public stockpiling and prices decrease significantly (see blue dotted curve on Figure 1) with availability, which eventually induces speculators to hold some stocks. Even if they are disincentivized and store much less than without the public policy, private storers are essential for achievement of welfare gains with a price-band program. A price-band program is designed to prevent prices from exceeding some values, but this does not guarantee that there will not be some remaining intertemporal profit opportunities. If authorized to operate, private storers will seize all the profit opportunities left by public storage. This role is essential as the remaining profit opportunities are so large under a price band that preventing private storers from operating is likely to result in welfare losses with respect to *laissez-faire*.

This important role of private storers is reminiscent of Salant's (1983) result that buffer-stock schemes are subject to speculative attacks. These speculative attacks are just the expression of the remaining profit opportunities left and created by a price-band scheme. The vulnerability of price-band schemes to speculative attack is not something that should be criticized: rather it is a feature of their limited behavior. Under a price-band program government intervenes only to defend the bounds and does not consider volatility inside or outside the bounds. Because there are profit opportunities beyond the bounds, speculators bring additional stabilization.

The optimal price band in Gouel (2013b) and in Figure 2 is a price peg: a policy in which the floor equals the ceiling, and with an occasionally binding maximum stock level. Since this result contradicts most practices and recommendations consisting of the use of large bands, it deserves some comment. This result is not specific to an optimal policy setting, it also arises in other studies analyzing the welfare cost of price bands. For example, Miranda and Helmberger (1988) show that the deadweight loss from a price-band program is lowest for a zero bandwidth. And in Williams and Wright (1991, Ch. 14), a price-peg scheme entails smaller losses than either a price band or a simple floor price without capacity constraint. Price pegs overcome one usual problem of price bands. With price bands, stocks are usually held for too long because nothing is sold between the bounds. With a price peg, this is not the case: as soon as government has acquired stock it stands ready to dispose of it if prices increase above the peg.

Since the optimal parameters of the price peg include a maximum stock level that will be occasionally binding, the price peg often fails: prices are regularly either below the target, because the maximum stock level has been reached, or above the target because public stock is exhausted. However, as it proceeds from a welfare maximization, this failure to defend the price-peg is intentional. The target price acts as a pretext for accumulating stocks beyond competitive levels to stabilize prices, and is not expected to be defended seriously.

In Gouel (2013b), other simulation results show that for different, but close, parameters, such as a larger maximum stock level or large bands instead of a peg, a price-band scheme could decrease welfare. Contrary to intuition and its presence in policy discussions, a price band may not be a very good simple rule. It is not robust. This is a highly non-linear rule, which can work well for some combinations of parameters, but which can work poorly for close combinations of parameters.

How does the optimal price band compare to price-band programs actually implemented? The practice seems completely opposite to the above recommendations. When price bands are relied on, they are often defined by large symmetric bands. On other occasions, the floor price is defined with precision but sales are decided discretionary. International Commodity Agreements are an example of the use of bandwidth rules to stabilize prices. The international cocoa, rubber, and tin agreements relied explicitly on symmetric bands around a target prices, which were regularly adjusted (Gilbert, 1996). In relation to national policies, a few countries, including Indonesia (Timmer, 2010), have relied on price band but what has been more common is a combination of floor price and discretionary sales. This applies to the European Union, where for several commodities a minimum price was guaranteed to farmers by public storage, but sales followed discretionary decisions by the European Commission. This applies also to India, where rice and wheat farmers benefit from minimum support prices. The procured public stocks are used partly to supply the public distribution system, but remaining stocks are managed with discretion.

These policies with large bands or weak selling provisions have been generally considered, when not complete failures, to be costly policies with uncertain benefits (Akiyama et al., 2001). This could be interpreted as confirmation of the conclusions from the literature on price bands. However, we should not exclude the possibility that price-band policies might be designed for objectives different from stabilization around a target price, for example, if the policy objective is related to preventing the occurrence of excessively high or low prices. The precise motivations for stabilizing food prices is still being debated (see Gouel, 2014, Section 2), so one should not exclude different conclusions about how price bands should best be designed.

6 The incidence of stabilization policies[7]

Optimal policies and optimal simple rules are designed to increase welfare, but it does not mean that they will increase the welfare of all agents. Since the work of Newbery and Stiglitz (1981), a recurrent criticism of price stabilization policies is that they generate redistribution between consumers and producers, more than efficiency gains. Indeed, stabilizing prices through storage or trade policies can affect agents' welfare in convoluted and counterintuitive ways. This is because it is difficult if not impossible to reduce price variance without changing the mean as well as other moments. If agents are assumed to be sufficiently risk averse, they may enjoy welfare gains from a reduced variance in prices or if a social preference for food price stability is assumed, we can expect aggregate efficiency gains for the economy. However, changes in the mean price will lead to transfers between consumers and producers which for some groups will potentially exceed the efficiency gains obtained from a reduced risk. The direction of the transfers between agents will be determined mainly by changes in the mean price and there are good reasons to expect stabilization policies to affect the mean price.

Stabilization can affect the mean price in both directions, and it is difficult to propose general results for the incidence of stabilization policies because this is influenced by several parameters. For example, the

[7] This section draws extensively on Gouel (2014).

incidence identified for long-run results can be reversed if dynamics is accounted for and long-run welfare changes are discounted. Welfare gains can be reversed depending on the hypotheses made about the nature of the shocks: multiplicative or additive, related to the demand curvature or the values of the elasticities. Since incidence is so dependent on setting, we describe some general mechanisms that affect the distribution of gains among agents (for more details on the incidence of price stabilization policies, see Wright, 1979, Wright and Williams, 1988).

Due to the high sensitivity of incidence results to the detailed context, this section relies less than previously on the results from rational expectations storage models.

6.1 Static incidence

Here we focus on static transfers, those that arise from a static model or from the stationary regime of a dynamic model. The mean price around which a policy stabilizes domestic prices depends on the details of the policy but some general conclusions can be drawn about this mean price by considering how price instability affects demand and supply behavior. The curvature of the demand function is a crucial element driving how stabilization policies affect the mean price. In many policies, the real objective is to stabilize food consumption not prices, and even if this is not the objective, stabilizing quantities is more convenient in practice since prices are the endogenous result of market equilibrium whereas it is possible to affect quantities through storage. If we focus on demand and neglect the supply reaction, a mean-quantity-preserving contraction will maintain the mean price constant if the demand function is linear. If demand is convex, a mean-quantity-preserving contraction (spread) leads to a lower (higher) mean price because the convexity implies that prices react more to changes to high consumption levels than changes to low consumption levels.

Supply reaction also matters for assessing incidence. The welfare of producers changes because of the new price distribution but also they react to this distribution by changing their supply. Let us consider a situation à la Sandmo (1971) in which producers are risk averse and produce less when faced with stochastic prices than in a certain environment, and complete the market by introducing futures which allow producers to hedge their price risk, with the result that they produce more. This is individually profitable. Each producer, by securing its selling price on the futures market, is able to commit more resources and enjoy more benefits. However, this can be collectively self-defeating. Increased production by all farmers results in a price distribution with a lower mean, which may decrease producers' welfare for inelastic demand and elastic supply (Myers, 1988, Lence, 2009). In the absence of other market failures, completing the market increases economic efficiency and generates aggregate welfare gains but with no guarantee that risk-averse agents will benefit.

6.2 Dynamic incidence

Stabilization policies are inherently dynamic, which means that their incidence should not be assessed only on the long-run equilibrium. It is important also to account for the way welfare gains are affected in the transition to this equilibrium. A public storage policy usually aims at stabilizing prices by accumulating stocks beyond competitive levels. So a storage policy begins with a transitory phase of stock accumulation before reaching its long-run behavior. Since stock purchases are higher than they would be without intervention, prices temporarily will be higher. We explained above that a stabilization policy in the long-run may lead to a price distribution with a lower mean, because of either supply reaction or demand convexity, thus potentially hurting producers' welfare. Because these long-run lower prices are discounted with respect to short-run high prices caused by stock accumulation, producers may actually enjoy a storage policy. This is the important conclusion in Miranda and Helmberger (1988) and Wright and Williams (1988) that the actual incidence of market-stabilizing policies is often dominated by what occurs in the transitory phase. The importance of transitional dynamics implies also that initial conditions matter a lot: it is not the same to start a policy when availability is high or low.

The other crucial point that affects the dynamic incidence of policies is capitalization. Agricultural production requires the use of a fixed factor, land. To the extent that other inputs are supplied elastically, the value of land is likely to include the effect of agricultural policies, potentially depriving farmers of welfare gains. Since the market value of farmland reflects the expected benefits tied to its operation and how much people are willing to pay to benefit from the insurance provided by farm programs, this value will increase with the introduction of policies that increase revenue or decrease revenue risk. Thus, the main beneficiaries of such a policy will be the owners of the farmland at the time the policy is implemented. In reality, the pass-through from policy benefits to land market values is not complete, but capitalization still allocates much of the gain to the current land owner (Kirwan, 2009, Goodwin et al., 2012).

7 Conclusions and discussion of the open issues

This paper provides an overview of recent research on the design of food price stabilization policies, and more specifically storage policies. It has shown that when a preference for food price stability is included in the social welfare function, optimally designed storage policies could increase welfare with respect to *laissez-faire*. But doing so is a tricky business, even in the controlled environment of a small calibrated model. This potentially casts doubt on the ability of policy makers to achieve it in real situations. The difficulties are mostly related to the fact that optimal stabilization policies are highly nonlinear policies (especially in open-economy settings), whose implementation is orthogonal to a private marketing system because an optimal storage policy would completely crowd out speculative private storage.

If food price stabilization policies have to be pursued, one solution may be to rely on optimal simple rules of intervention such as price band or subsidy to private storers. These rules should be more compatible with the presence of private speculation since they rely in part or completely on its presence (without private storers, price-band schemes can generate welfare losses with respect to *laissez-faire*). These optimal simple rules have been shown in a variety of contexts to be able to achieve welfare results almost as good as fully optimal policies.

The setup used to derive optimal policies is simple and provides many valuable insights. Some of them, although consistent with earlier work, contradict certain practices and policy recommendations (e.g., the usual recommendation that price bands should be large). Given the importance of the question, it would be interesting to know how sensitive these results are. In what follows I consider a few open questions that could qualify my conclusions, but to which as yet there are no clear answers.

One is definition of a good benchmark. The efficiency gains are measured with respect to *laissez-faire*, and in this situation, private storers do a very good job at stabilizing prices. Since private storers already arbitrate the largest price fluctuations, any additional stabilization is costly to achieve. To consider that private storage would operate flawlessly in poor countries might be assuming too much. Also there is little evidence regarding the behavior of inter-annual private storage in developing countries. In the competitive storage model, storers operate in expectations of zero profit but their realized profit is extremely volatile and would require the firm involved to have large financial capacity. In the presence of futures markets, the price risk can be shared with financial speculators, and storers' risk attitudes will not affect their storage behavior. But well-functioning futures markets are not a defining features of developing countries' staple food markets. Another risk that may hinder the development of private inter-annual storage is that created by government. Because of the consequences of high food prices on social stability (Arezki and Brückner, 2011), governments in poor countries cannot commit to *laissez-faire*, and knowing that, private agents will be reluctant to serve these markets (Wright and Williams, 1982b).

The literature on buffer-stock policies relies exclusively on inter-annual storage models because it tries to answer the question of how much grain to carry from one harvest to the next. While this approach seems to be adequate as a first step, there are some features of intra-annual storage that might deserve further analysis in the context of a stabilization policy, and any realistic stabilization policy has to deal with how to dispose of public stocks over the whole year. While following the same intertemporal arbitrage equation, intra-annual storage is also about making available for consumption during all the year some commodity that can only be produced at some periods. One limiting feature of inter-annual storage models is that uncertainty is resolved all in one period, while the reality of commodity markets is that there are news shocks that accumulate along the coming harvest (Osborne, 2004). These pieces of information can be used to adjust stocks before observing the harvest effectively. So, contrary to the framework used above, managing stocks intra-annually involves making decisions while using optimally partial information on future shocks. This may matter a lot, for example, on questions of trade. When trade takes time (Coleman, 2009), shipments may have to be ordered with limited knowledge of the coming harvest.

Another issue is the question of price-band programs. For most people, price bands are synonymous with buffer-stock policies but their performance in theory and in calibrated models has raised doubts in the literature about their usefulness. A future area for research could be to attempt to address this divide between policy advice and practice, for example, by considering the design of price-band policies that are closer to practice. In reality, bands are not constant, they are adjusted regularly based on the new market conditions (Gilbert, 1996). Would a different design work better, and what should be the rules to update bands? Lastly, in an open economy, the performance of price band is an open question.

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