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Trade Policy Coordination and Food Price Volatility

Christophe Gouel

Highlights

- The countercyclical adjustments of trade policies with food prices are an important contribution to the volatility of food price.
- We study in a theoretical model the features of an international agreement to discipline their use.
- Even in cooperation, it is not possible to exclude deviation from free trade as incentive to deviate from cooperation could become too high in free trade in case of large shocks.
- Given that the distribution of staple food prices is positively skewed, food exporter will occasionally face large incentive to deviate from free trade, thus, disciplining export taxes will be more difficult than tariffs in trade agreements.

Abstract

Many countries adjust their trade policies countercyclically with food prices, to the extent that the use by numerous food exporters of export restrictions has occasionally threatened the food security of food importing countries. These trade policies are inconsistent with the terms-of-trade motivation often retained to characterize the payoff frontier of self-enforcing trade agreements, as they can worsen the terms of trade of the countries that apply them. This paper analyzes trade policy coordination when trade policies are driven by terms-of-trade effects and a desire to reduce domestic food price volatility. This framework implies that importing and exporting countries have incentives to deviate from cooperation at different periods: the latter when prices are high and the former when prices are low. Since staple food prices tend to have asymmetric distributions, with more prices below than above the mean but with occasional spikes, a self-enforcing agreement generates asymmetric outcomes. Without cooperation, an importing country uses more frequently its trade policy because of the concentration of prices below the mean, but an exporting country has a greater incentive to deviate from a cooperative trade policy because positive deviations from the mean price are larger than negative ones. Thus, the asymmetry of the distribution of commodity prices can make it more difficult to discipline export taxes than tariffs in trade agreements.

Keywords

Commodity price stabilization, export restrictions, repeated game, WTO.

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F13, Q17, Q18.

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RESEARCH AND EXPERTISE ON THE WORLD ECONOMY

Trade Policy Coordination and Food Price Volatility[1]

Christophe Gouel*

1. Introduction

During food price spikes, food exporting countries frequently use export restrictions to insulate their domestic markets from high prices on the world market. Their use can be so widespread that the high levels reached by international prices could be seen as a consequence of these interventions (Dawe and Slayton, 2011), and the restrictions can be so stringent that they can lead to the near disappearance of the world market as happened to the rice market over nine months in 1973 (Timmer, 2010). Food importing countries also do not remain inactive: they decrease their tariffs to protect their consumers. When world prices are low, the situation is reversed: importers raise their import duty. In summary, in food markets countries routinely adjust their trade barriers to insulate their domestic markets from international price variability (Anderson and Nelgen, 2012). The lack of commitment to leaving borders open can reduce trust in the world trade system and lead to costly policies. Importing countries that expect food exporters to restrict their exports in times of scarcity will move away from a specialization consistent with their comparative advantages, to ensure a higher self-sufficiency, or will carry expensive public stocks. For example, the current large-scale public interventions in the Asian countries, through which many countries attempt to achieve self-sufficiency in major staples, can be explained largely by their experience of the 1972/73 food crisis (Rashid et al., 2008).

The widespread use of export restrictions in the 2007/08 food prices spike,[2] and the Russian ban on exports in 2010 after a devastating drought, spurred call for World Trade Organization (WTO) disciplines on export restrictions (FAO et al., 2011, HLPE, 2011, Bouët and Laborde, 2012). These proposals received a cold reception from several food-exporting developing countries (Mitra and Josling, 2009), and were not considered in the agreement reached at the 9th WTO Ministerial Conference held in Bali (WTO, 2013).[3] So far, according to agricultural draft modalities (WTO,

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[2]In a survey of country responses to the food security crisis, Demeke et al. (2009) show that 25 developing and emerging countries in a panel of 81 restricted or banned exports.
[3]This was not a new issue as proposals to regulate export restrictions were rejected by many member countries at the beginning of the Doha Round negotiations (WTO, 2004).

2008), in the case of another agreement there would not be any significant strengthening of the disciplines on export restrictions. Given the importance of export restrictions for influencing trust in world markets, and thus food policies in the long run, it is essential to understand what is preventing a trade agreement on this issue. This paper contributes to understanding of what trade agreements would be acceptable with respect to trade policies that are countercyclical with food prices. Using some concepts of game theory, it explores the possibility of cooperation through a self-enforcing trade agreement between countries which, on their own, would try to decrease the volatility of their domestic food prices via trade policies.

A formal treatment of countercyclical trade policies, and the extent to which self-enforcing agreements can discipline countercyclical trade policies are proposed in Bagwell and Staiger (1990, 2003). An agreement is self-enforcing when cooperation is sustained by the threat of future punishment if cooperation is violated, without the need for an external enforcement mechanism. Bagwell and Staiger (1990, 2003) show that the threat of a return to a non-cooperative situation is sufficient to obtain tacit cooperation among countries involved in repeated interactions. However, this cooperation is not necessarily synonymous with free trade, because when trade shocks are large enough the incentive to deviate from cooperation would become too high in free trade. The papers by Bagwell and Staiger focus on trade policies motivated by terms-of-trade gains, and explain changes in trade policies by changes in potential terms-of-trade gains arising from idiosyncratic supply shocks. For food products, terms-of-trade theory may not be sufficient to explain the behavior of trade barriers. Examples of deviations from this theory are the export bans imposed by many countries during the recent food crisis that precluded any gains from trade, and the export subsidies applied by wealthy countries in periods of low prices which deteriorate the terms of trade of the countries using them. In addition, terms-of-trade theory relates trade policy adjustments to trade volume rather than to the world price, because trade volume characterizes the potential gains from manipulating terms of trade. However, Anderson and Nelgen (2012, Table 1) show that protection of food products is negatively correlated with deviations from trend in the international price of the products in question. So to account for the extent of trade policy adjustments in food products, and to characterize the payoff frontier of self-enforcing trade agreements, we need a model where governments are not just motivated by terms-of-trade gains, but want also to stabilize domestic prices.

Our starting point is the two-country partial equilibrium model proposed by Bagwell and Staiger (1990). There are two features that distinguish our model from Bagwell and Staiger's. Firstly, to investigate the impact of price fluctuations on trade policy coordination, a particular structure must be placed upon the social welfare function since exploitation of the terms of trade is not sufficient to explain the offsetting of international price variations by trade policies. To introduce the observed reaction of trade policies to the world price, it is necessary to consider other economic and political-economy motivations. Countercyclical trade policies can be rationalized as insurance instruments when accounting for market failures in risk management (Eaton and Grossman, 1985, Cassing et al., 1986, Gouel and Jean, forthcoming). Their existence might also be explained by political-economy considerations. For example, the loss-aversion framework of Freund and Özden (2008) and Tovar (2009) was applied by Giordani et al. (2014) to account for price-insulating trade policies. Given the variety of potential motivations for these policies (Swinnen, 2010, Anderson et al., 2013), and the focus of the present paper on the strategic interactions of countries, we adopt a tractable reduced-form social welfare function that accounts for the economic and political-economy motivations described above. Secondly, in contrast to Bagwell and Staiger's model which was concerned only with idiosyncratic risk, we introduce aggregate uncertainty, which is crucial to add world price volatility to the model. The resulting model is used to characterize the static Nash equilibria and the nature of a self-enforcing agreement on time-varying trade policies. The combination of the reduced-form social welfare function with aggregate uncertainty implies that in tacit cooperation equilibria, importing and exporting countries have incentives to deviate from cooperation at different periods: exporters when prices are high and importers when prices are low.

In addition to contributing to the theoretical literature on self-enforcing trade agreements, this paper contributes to the policy discussions on export restrictions. Despite the potential usefulness of disciplines on export restrictions, a few papers have pointed out that they are unlikely to be achievable in the WTO framework. For Abbott (2012), this is because policy makers will not agree to renounce their right to stabilize their markets. For Cardwell and Kerr (2014), the dispute settlement system cannot enforce such disciplines because export restrictions are of short duration compared to the time taken to settle disputes, and because complainant countries may not be in a position to retaliate owing to insufficient bilateral trade levels. In the present paper, disciplines on export restrictions are also proved difficult to achieve. Since staple food prices tend to have positively-skewed distributions (Deaton and Laroque, 1992), with more prices below the mean than above it, but with occasional spikes, a self-enforcing agreement generates asymmetric outcomes. Although an importing country suffers less in trade war than an exporting country, the latter has a greater incentive to deviate from a cooperative trade policy because positive deviations from the mean price will be larger than negative ones. Thus, due to the asymmetry of the distribution of commodity prices, it may be more difficult to discipline export taxes in trade agreements, than tariffs.

The remainder of the paper is organized as follows. Section 2 presents the model under free trade and equilibrium under given trade policies. Section 3 characterizes the social welfare functions and solves the static Nash equilibria resulting from each country's social welfare maximization. The interior Nash equilibrium is used subsequently as a credible punishment in the dynamic game. Section 4 characterizes analytically the tacit cooperative equilibrium, and section 5 illustrates numerically the results under symmetric and asymmetric price distributions. Section 6 concludes.

2. Model setup

Consider a partial equilibrium model of a global cereal market. There are two countries (Home and Foreign) with identical demand schedules. Foreign is indicated by the superscript "$*$". Production is assumed to be inelastic and is represented by two stochastic shocks, ε and ε^*, which are drawn from known probability distributions defined on bounded supports and which are not serially correlated. Production shocks are perfectly observable. They are such that in free trade Home is always in a position to export to Foreign, so to ensure $\varepsilon \geq \varepsilon^*$ the distribution of ε is assumed to dominate absolutely the distribution of ε^*.

Demand is represented by an inverse demand function $D(P)$ assumed to be linear and identical in both countries $D(P) = a - bP$ and $D^*(P^*) = a - bP^*$. Domestic prices clear the markets: $\varepsilon = D(P) + V$ and $\varepsilon^* = D^*(P^*) - V$, where V refers to the volume of trade.

Countries can apply specific trade taxes: τ and τ^*. When trade takes place, domestic prices are defined by combining the world price, P^w, with trade policies:

$$P = P^w + \tau \text{ and } P^* = P^w + \tau^*. \tag{1}$$

This definition implies that when Home exports, a negative τ is an export tax; conversely, when Foreign imports, a positive τ^* is an import tax.

By combining the above equations, we can characterize the volume of trade:

$$V = \frac{\varepsilon - \varepsilon^*}{2} + \frac{b(\tau - \tau^*)}{2}. \tag{2}$$

From (2), the free-trade trade volume is defined as $V^f \equiv (\varepsilon - \varepsilon^*)/2$. Trade is strictly positive for

$$\tau - \tau^* > \frac{\varepsilon^* - \varepsilon}{b} \text{ or } \tau^* - \tau < \frac{2V^f}{b}. \tag{3}$$

When (3) holds, world price is given by

$$P^w = \frac{a - (\varepsilon + \varepsilon^*)/2}{b} - \frac{\tau + \tau^*}{2}. \tag{4}$$

In a situation of free trade, the world price would be $P^f \equiv a/b - (\varepsilon + \varepsilon^*)/(2b)$.

Let s be the state of the world. It is defined by the two supply shocks ε and ε^*. Another equivalent definition of the state of the world that proves useful later in the paper is the aggregate risk, $\varepsilon + \varepsilon^*$ and the difference in idiosyncratic risks, $\varepsilon - \varepsilon^*$, which can also be represented by the free-trade world price, P^f, and the free-trade trade volume, V^f.

3. The static game

In this section, we characterize the Nash equilibria of the static game in which each country applies the trade taxes maximizing a social welfare function which, in addition to the usual measures of surplus, accounts for the policy-makers' preference for food price stability. The resulting interior trade policies are costly for both countries and will serve as punishments in the repeated game.

3.1. Social welfare function

Given that this paper focuses on the strategic interactions of countries that insulate their markets, we adopt a tractable reduced-form social welfare function able to account for various economic and political-economy motivations and which allows trade policies to vary countercyclically with the world price according to the stylized facts (Anderson and Nelgen, 2012). We assume that governments maximize their country's welfare which is defined as the sum of the producer's surplus, the consumer's surplus, and the tariff revenue to which a quadratic term in the domestic price is added to account for the policy-makers' preference for food price stability. Home and Foreign welfare functions are defined as functions of the state of the world and the trade policies by

$$W(s,\tau,\tau^*) \equiv \int_{P(s,\tau,\tau^*)}^{a/b} D(p)\,\mathrm{d}p + P(s,\tau,\tau^*)\,\varepsilon - \tau V(s,\tau,\tau^*) - \frac{K}{2}\left[P(s,\tau,\tau^*) - \bar{P}\right]^2, \tag{5}$$

$$W^*(s,\tau,\tau^*) \equiv \int_{P^*(s,\tau,\tau^*)}^{a/b} D^*(p)\,\mathrm{d}p + P^*(s,\tau,\tau^*)\,\varepsilon^* + \tau^* V(s,\tau,\tau^*) - \frac{K}{2}\left[P^*(s,\tau,\tau^*) - \bar{P}\right]^2, \tag{6}$$

where $K \geq 0$ is a parameter characterizing the preference for price stability and $\bar{P}$ is a target price around which policy-makers want prices to be stabilized. $\bar{P}$ is taken as the steady-state, free-trade price, or the price when shocks are equal to their expectations, and when countries do not use trade policies. Given the linearity of the model, the steady-state, free-trade price is equal also to the average price without intervention. For simplicity, the preference for price stability and the target price are assumed to be identical in both countries.

3.2. Trade policies as function of world price

Before considering the Nash equilibrium, we analyze how trade policies react to the world price when countries maximize their social welfare function as defined above. To get the optimal reaction to world price changes, we maximize $W(s,\tau,\tau^*)$ over $\tau \leq 0$ and $W^*(s,\tau,\tau^*)$ over $\tau^* \geq 0$. The welfare functions are strictly concave with respect to their domestic trade policy, so the optimal trade policies are given by the first-order conditions, which if (3) holds leads to:

$$\tau = \min\left[0, \frac{\overbrace{K(\bar{P} - P^w)}^{\text{Smoothing}} - \overbrace{(\varepsilon - a + bP^w)}^{\text{Market power}}}{K + 2b}\right], \tag{7}$$

and to a similar expression for Foreign trade policy.

This trade policy has two components. The first component obeys a smoothing motive. It is countercyclical and will tend to impose export subsidies when prices are below the target price, and export taxes when prices are above the target price. The second component exploits the country's market power. It leads to the use of export taxes to exploit market power over world price, and as is clear from the equation, this component is proportional to the trade volume at the border price $(\varepsilon - D(P^w))$. For $K = 0$, this is the only rationale for intervention.[4]

3.3. The interior Nash equilibrium

Next, we characterize the interior Nash equilibrium and express all results as functions of P^f and V^f. From equation (7), best-response correspondences are given by

$$\tau_R(s, \tau^*) = \min \left[0, 2\frac{K(\bar{P} - P^f) - V^f}{K + 3b} + \frac{K + b}{K + 3b}\tau^* \right], \tag{8}$$

$$\tau_R^*(s, \tau) = \max \left[0, 2\frac{K(\bar{P} - P^f) + V^f}{K + 3b} + \frac{K + b}{K + 3b}\tau \right]. \tag{9}$$

For each country, the interior Nash trade policies present three possible regimes. For sufficiently low prices $(P^f \leq \bar{P} - bV^f/K(K + 2b))$, the unconstrained policy for the exporter would be to subsidize its exports. Because its policy is constrained to be a tax, it does not impose any trade barrier. In this case, the importer policy is set by (9) with $\tau = 0$. The opposite is true for sufficiently high prices $(P^f \geq \bar{P} + bV^f/K(K + 2b))$: no trade policy on the importer side, and exporter trade policy determined by (8). For intermediate prices, trade policies in each country account for the intervention in the other country. This is summarized by the following expressions:

$$\tau_N(s) = \begin{cases} 0 & \text{if } P^f < \bar{P} - \frac{bV^f}{K(K+2b)}, \\ \frac{K(\bar{P} - P^f)}{b} - \frac{V^f}{K+2b} & \text{if } \left|\bar{P} - P^f\right| \leq \frac{bV^f}{K(K+2b)}, \\ 2\frac{K(\bar{P} - P^f) - V^f}{K+3b} & \text{if } P^f > \bar{P} + \frac{bV^f}{K(K+2b)}, \end{cases} \tag{10}$$

$$\tau_N^*(s) = \begin{cases} 2\frac{K(\bar{P} - P^f) + V^f}{K+3b} & \text{if } P^f < \bar{P} - \frac{bV^f}{K(K+2b)}, \\ \frac{K(\bar{P} - P^f)}{b} + \frac{V^f}{K+2b} & \text{if } \left|\bar{P} - P^f\right| \leq \frac{bV^f}{K(K+2b)}, \\ 0 & \text{if } P^f > \bar{P} + \frac{bV^f}{K(K+2b)}, \end{cases} \tag{11}$$

where the subscript N designates variables on the Nash equilibrium. Again we find in these expressions the two components of smoothing and market power. Terms proportional to $\bar{P} - P^f$ relate to smoothing, and terms proportional to V^f relate to market power. They behave very differently.

[4] With a small country, the optimal trade policy would be $\tau = \min [0, K(\bar{P} - P^w) / (K + b)]$. This is similar but slightly different from the smoothing component of (7). With respect to the smoothing objective, a small country reacts more to world price change than a big country, for which the use of countercyclical trade policies amplifies world price movement and so hurts its smoothing objective. However, when accounting for the terms-of-trade motivation, a big country adjusts more its trade policy with world price changes than a small country, because the ratio of the slopes of the trade policy rules with respect to world price is $K(K + 2b) / (K + b)^2$, which is always inferior to 1.

The market power components have opposite signs in the two countries. Given the world price equation (4), this means that for intermediate world price levels, when policies are unconstrained, these components do not change the world price. The exporter tends to tax exports, and the importer tends to tax imports. It reduces trade levels, leaves the world price unchanged, reduces prices in the exporter, and increases prices in the importer.

In contrast, for intermediate world price levels, the component of trade policy motivated by smoothing is equal across countries and does not affect the domestic price. Each country tries to bid more for the same commodity. In a situation of scarcity, the exporter increases its export tax, and the importer decreases its tariff by the same amount, so the quantities allocated are the same. The terms of trade of the exporter improve at the expense of the importer, thus, a transfer has taken place from the importing to the exporting country. In a situation of glut, the situation is reversed: the exporter decreases its export tax and the importer increases its tariff, so this smoothing component leads to transfers from the exporting to the importing country. These policy adjustments perfectly offset each other, and so are inefficient. This inefficiency of countercyclical trade policies at the global level is highlighted in Bigman and Karp (1993) and Martin and Anderson (2012).

Martin and Anderson (2012) compare this inefficiency of the countercyclical component of trade policies to the collective-action problem which arises when a crowd stands up in a stadium to get a better view: when everybody is standing then standing up does not result in a better view, but remaining seated is no longer an option. In our framework, this zone of compensation does not justify an international cooperative agreement with respect to the smoothing motivation, because the only aggregate welfare cost is related to the terms-of-trade part of the intervention. Since the smoothing parts of trade policies compensate each other, they do not affect domestic prices but create income transfers associated with the terms-of-trade changes. Across time, these transfers compensate because the target price is also the average price. In our welfare framework, given the absence of aversion to income risk, this volatility of income is not costly. The smoothing motivation for trade policies opens the possibility for a trade agreement precisely when policies do not compensate: for a low or high free-trade world price when one country is constrained in its trade policy.

This is what motivates here restricting trade policies to be taxes. In the model, trade policies are constrained to be taxes to prevent a subsidy in one country to perfectly offset the effect of a tax in the other country. Without this restriction, the smoothing component of trade policies would not generate any aggregate welfare losses because of the perfect compensation of subsidies by taxes. This is not to deny the actual use of subsidies, but to account that for various reasons, including fiscal reasons, their use is unlikely to be as extensive as the use of trade taxes. The results in this paper would be similar, if instead of assuming that countries are constrained to use trade taxes, they were constrained to not exceed a certain level of subsidies. Such a constraint would maintain the existence of states of the world in which the smoothing components of trade policies do not offset each other.

Given the use by the two countries of these Nash trade policies, the world price is given by

$$P_N^w = P^f + \begin{cases} \frac{K\left(P^f - \bar{P}\right) + V^f}{K+3b} & \text{if } P^f < \bar{P} - \frac{bV^f}{K(K+2b)}, \\ \frac{K\left(P^f - \bar{P}\right)}{b} & \text{if } \left|\bar{P} - P^f\right| \leq \frac{bV^f}{K(K+2b)}, \\ \frac{K\left(P^f - \bar{P}\right) - V^f}{K+3b} & \text{if } P^f > \bar{P} + \frac{bV^f}{K(K+2b)}. \end{cases} \tag{12}$$

These trade policies amplify the movements in the free-trade price and this amplification depends on K. A higher preference for domestic price stability entails a higher volatility of the world price (see also Giordani et al., 2014, for an in-depth analysis of this multiplier effect of trade policy). With respect to free trade, the world price will be increased by trade policies if the free-trade price is above the target price, and decreased when it is below (see figure 1). The world price equals the free-trade price only when the free-trade price equals the target price. These trade policies increase the world price variance with respect to the free-trade situation. This increased variance is caused by the smoothing motivation (the world price variance would be the same as in free trade if K equal 0).

The model has two exogenous variables that define its state: the free-trade world price, P^f, and the free-trade trade volume, V^f (or equivalently ε and ε^*). The free-trade world price represents the aggregate risk as it is determined by the overall production level, that is the sum of production shocks in the two countries. In free trade, for the same world price, there can be different levels of trade volume depending how production is divided between the countries, thus, the free-trade trade volume represents the idiosyncratic risk. Focusing on the two special cases of pure aggregate risk and pure idiosyncratic risk presents interesting contrasts that contribute to our analysis of these policies.

Pure aggregate risk In a situation where $\varepsilon - \varepsilon^*$ is a constant, there is an aggregate supply risk only, and no idiosyncratic risk. This leads to a constant free-trade trade volume but a volatile free-trade price, and according to (10) and (11), changes in trade policy are explained only by the smoothing motivation. However, strategic interactions and market power considerations are present. For intermediate world prices, the slope of the trade policy rule with respect to the free-trade price is $-K/b$, while it would be smaller at $-K/(K+b)$ in a small country. Indeed in the Nash equilibrium, larger countries adjust their trade policies more to the world price than would a small country in an attempt to compensate for their partner's trade policy when this latter is active.

Pure idiosyncratic risk If $\varepsilon + \varepsilon^*$ is a constant, there is no aggregate risk, only idiosyncratic risk (this is the situation analyzed in Newbery and Stiglitz, 1984, and Bagwell and Staiger, 1990). The free-trade price and the smoothing component of trade policies are constant. In this situation, the change in trade policies stemming from the terms-of-trade motivation appears

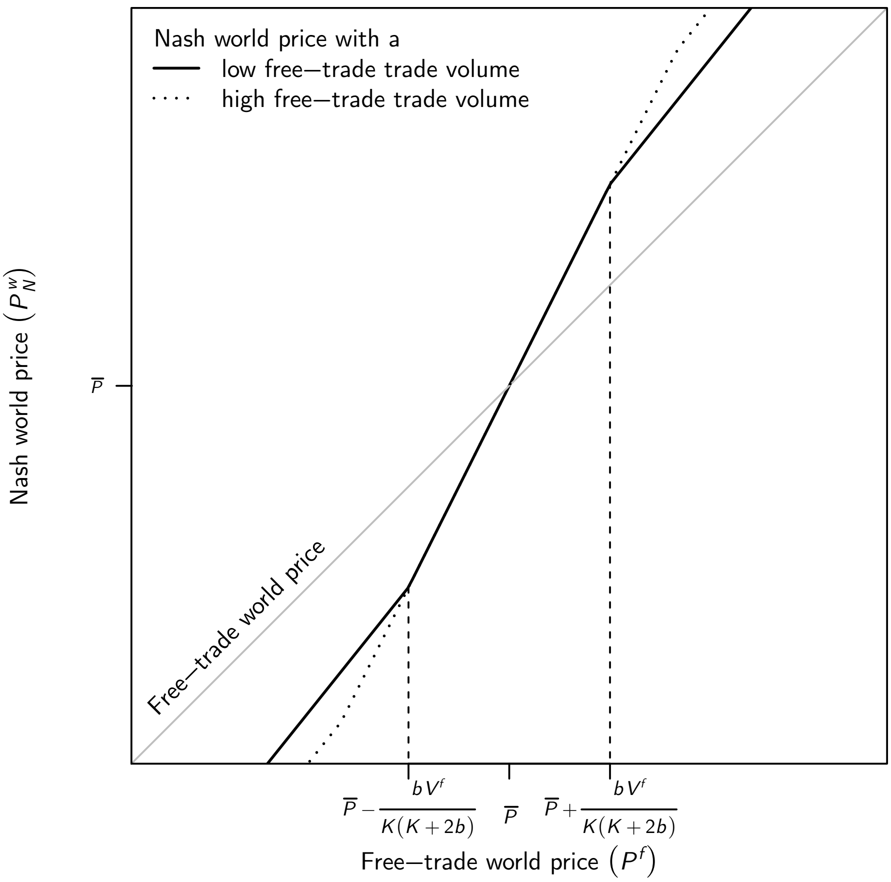

Figure 1 – Interior Nash world price (P_N^w) as a function of free-trade world price (P^f) for two levels of free-trade trade volume (V^f)

to be in conflict with the desire for smoothing. Without trade policy intervention, the world price would be constant but potential terms-of-trade gains compel countries to intervene. This creates a trade-off between the smoothing and terms-of-trade motivations. This is shown in equations (10) and (11) in the slope of trade policy with respect to the free-trade trade volume: for an intermediate world price, without the smoothing motivation in the social welfare function, the slope would be $1/2b$, whereas it is actually $1/(K+2b)$. The slope is reduced by the smoothing motive, since pursuit of terms-of-trade gains goes against it.

One intuition about trade policies motivated by price smoothing is that they may hinder international sharing of agricultural production risk. Agricultural production is much more volatile at the country than at the world level, because the pooling of all idiosyncratic weather shocks leads to much more stable aggregate production. The two extreme cases analyzed above show that the smoothing component of trade policies does not try to prevent risk sharing, and it is equal to zero when only idiosyncratic risk is present. Smoothing-related trade policies are motivated only by aggregate shocks.

3.4. The autarky equilibria

We now turn to the Nash equilibria that correspond to autarky. If $-\tau \geq 2V^f/b$ or $\tau^* \geq 2V^f/b$ then, whatever the value of the other country's trade policy, condition (3) does not hold and autarky prevails. So there is a set of Nash equilibria without trade for any trade tax pair in which one of the taxes, in absolute value, exceeds $2V^f/b$.

3.5. Efficient trade policies

The trade policies that maximize joint welfare, $W(s,\tau,\tau^*)+W^*(s,\tau,\tau^*)$, are defined by

$$\tau = \tau^*, \tag{13}$$

which, considering trade policies constrained to be taxes, is compatible only with free trade. So the interior Nash equilibrium is inefficient, because it features too little trade and too much price volatility.

4. International cooperative agreement

We now consider that the countries interact repetitively which enables them to coordinate on more cooperative policies. In this dynamic game, based on the observed state variables, countries decide their trade policy at each period. They can coordinate on lower protection levels than in the static game, because cooperation is enforced by the threat of forever reverting to the interior Nash equilibrium if one country deviates from cooperation.[5] Since we want to analyze what would be best and most credibly achieved by such coordination, we consider trade policies that are subgame perfect.

Even in cooperation, free trade may not always be sustainable, because the long-run gains from cooperation may not exceed the short-run gains from deviation when world price is very high or very low. To understand when countries could be susceptible to defecting from cooperation, we characterize their incentives to do so. The short-run gains of deviating from the cooperative trade policies $\{\tau_c,\tau_c^*\}$ are represented by $\Omega(s,\tau_c,\tau_c^*) \equiv W_D(s,\tau_c^*) - W(s,\tau_c,\tau_c^*)$ and $\Omega^*\left(s_t,\tau_{c,t},\tau_{c,t}^*\right) \equiv W_D^*(s,\tau_c) - W^*(s,\tau_c,\tau_c^*)$, where $W_D(s,\tau_c^*) = \max_{\tau\leq 0} W(s,\tau,\tau_c^*)$ is the welfare in case of deviation, that is, when the country's trade policy is given by its best-response correspondence (8).

[5] Reverting forever to the interior Nash equilibrium is not renegotiation proof. A renegotiation-proof agreement would have to include a return to cooperation after the punishment. This would make the analysis of the dynamic game more complex without affecting substantially the results. A renegotiation-proof agreement would imply less severe punishments following a deviation, and so could not sustain the same level of cooperation as sustained by the threat of forever reverting to the Nash.

Using the envelope theorem, we can characterize the behavior of the static gains from defection with respect to the state variables. With respect to the free-trade trade volume we have $\mathrm{d}\Omega(s,\tau_c,\tau_c^*)/\mathrm{d}V^f = -[\tau_R(s,\tau_c^*)-\tau_c]/2$ and $\mathrm{d}\Omega^*(s,\tau_c,\tau_c^*)/\mathrm{d}V^f = [\tau_R^*(s,\tau_c)-\tau_c^*]/2$. As in Bagwell and Staiger (1990), provided that the trade policy under deviation is farther from free trade than the cooperative policies (i.e., $\tau_R(s,\tau_c^*) < \tau_c$ and $\tau_R^*(s,\tau_c) > \tau_c^*$), the static gain from deviation increases with the trade volume, because the potential terms-of-trade gains are larger with a larger volume of trade.

For the behavior of the short-run gains from defection with respect to the free-trade world price we have $\mathrm{d}\Omega(s,\tau_c,\tau_c^*)/\mathrm{d}P^f = -K\left[\tau_R(s,\tau_c^*)-\tau_c\right]/2$ and $\mathrm{d}\Omega^*(s,\tau_c,\tau_c^*)/\mathrm{d}P^f = -K\left[\tau_R^*(s,\tau_c)-\tau_c^*\right]/2$. Provided that the trade policy under deviation is farther from free trade than the cooperative policies, the incentives to defect are asymmetrical. The exporting country has more incentives to defect when the world price is high, while the importing country has more incentives to defect when the world price is low.

Since we focus on subgame perfect trade policies, the cooperative trade policies are functions only of the payoff-relevant variables which are the current state variables, not past history: $\tau_c = \tau_c(s)$ and $\tau_c^* = \tau_c^*(s)$. Given that trade policies are functions only of state variables, and state variables have no intrinsic dynamics (the state variables, ε and ε^*, are not serially correlated), beyond current period we can define the expected future welfare gain from cooperation by $\omega(\tau_c(\cdot),\tau_c^*(\cdot)) \equiv \mathrm{E}_s[W(s,\tau_c(s),\tau_c^*(s)) - W(s,\tau_N(s),\tau_N^*(s))]$ and similarly for Foreign.

For each country, there is a trade-off between the short-run gains from deviation and the long-run losses from returning to the Nash equilibrium. To ensure that countries have no incentive to deviate, the following participation constraints have to be respected for all states s:

$$\Omega(s,\tau_c(s),\tau_c^*(s)) \leq \frac{\beta}{1-\beta}\omega(\tau_c(\cdot),\tau_c^*(\cdot)), \tag{14}$$

$$\Omega^*(s,\tau_c(s),\tau_c^*(s)) \leq \frac{\beta}{1-\beta}\omega^*(\tau_c(\cdot),\tau_c^*(\cdot)), \tag{15}$$

where $\beta \in [0,1)$ is the discount factor. These participation constraints convey the lack of commitment of each country. They do not commit to respect cooperative policies whatever the situation. Cooperation is possible as long as in any situation the cooperative policy is such that it satisfies these constraints. The equilibrium has to be self-enforcing.

The set of trade policies satisfying the participation constraints is not empty since Nash trade policies always satisfy them. We can show also that if the discount factor is sufficiently high, free trade is sustainable. Let us define $L(s,\beta) \equiv \Omega(s,0,0) - \omega(0,0)\beta/(1-\beta)$, the discounted future loss of Home from deviating from free trade. We have $L(s,0) > 0$ and $\lim_{\beta\to 1} L(s,\beta) = -\infty$, so by the continuity of $L(s,\beta)$ in β there exists $\overline{\beta} \in (0,1)$ such that $L(s,\beta) \leq 0$ if $\beta \geq \overline{\beta}$. The same applies to Foreign.

Corresponding to the participation constraint of Home, the threshold parameter is the discount factor such that $\Omega(\bar{s},0,0)-\omega(0,0)\beta/(1-\beta)=0$, where $\bar{s}$ is the state of the world that maximizes $\Omega(s,0,0)$. Given that Ω increases with P^f and increases with V^f, $\bar{s}$ corresponds to a situation of high trade volume and high price. This is similar for the Foreign participation constraint, except that since Ω^* decreases with P^f, the threshold discount factor parameter will be determined by the maximum value of Ω^*, which will be a low price combined with a high trade volume. Except when the distributions of production shocks are symmetric, they are unlikely to be equal and the threshold parameter for both constraints is just the maximum over each one:

$$\overline{\beta}=\max\left[\frac{\Omega(\bar{s},0,0)}{\Omega(\bar{s},0,0)+\omega(0,0)},\frac{\Omega^*(\bar{s}^*,0,0)}{\Omega^*(\bar{s}^*,0,0)+\omega^*(0,0)}\right]. \tag{16}$$

When the discount factor falls strictly below $\overline{\beta}$, free trade is not sustainable, but there is an infinity of trade policies that satisfy these constraints. We focus on the most cooperative subgame perfect Nash equilibrium, the trade policies that maximize intertemporal joint welfare while satisfying participation constraints. Another way to see this problem is to consider that it is the problem of a planner that tries to find the time-consistent trade policies that maximize joint welfare while satisfying the countries' participation constraints. This amounts to solving at each period t the following maximization problem:

$$\max_{\tau_t\le 0,\tau_t^*\ge 0} W(s_t,\tau_t,\tau_t^*)+W^*(s_t,\tau_t,\tau_t^*)+\frac{\beta}{1-\beta}\mathrm{E}_s\left[W(s,\tau_c(s),\tau_c^*(s))+W^*(s,\tau_c(s),\tau_c^*(s))\right] \tag{17}$$

subject to the participation constraints, (14) and (15). Given that the problem has no intrinsic dynamics and that we are focusing on the subgame perfect equilibrium, all expectations terms are in fact constants which are functions of the optimal cooperative policies.

Constraining trade policies to be taxes and associating positive Lagrange multipliers, μ_t and μ_t^*, to equations (14) and (15), the above problem gives the following first-order necessary conditions:

$$(1+\mu_t)\frac{\partial W(s_t,\tau_t,\tau_t^*)}{\partial\tau_t}+(1+\mu_t^*)\frac{\partial W^*(s_t,\tau_t,\tau_t^*)}{\partial\tau_t}-\mu_t^*\frac{\partial W_D^*(s_t,\tau_t)}{\partial\tau_t}\ge 0,\ =0 \text{ if } \tau_t<0, \tag{18}$$

$$(1+\mu_t^*)\frac{\partial W^*(s_t,\tau_t,\tau_t^*)}{\partial\tau_t^*}+(1+\mu_t)\frac{\partial W(s_t,\tau_t,\tau_t^*)}{\partial\tau_t^*}-\mu_t\frac{\partial W_D(s_t,\tau_t^*)}{\partial\tau_t^*}\le 0,\ =0 \text{ if } \tau_t^*>0, \tag{19}$$

$$\Omega(s_t,\tau_t,\tau_t^*)-\frac{\beta}{1-\beta}\omega(\tau_c(\cdot),\tau_c^*(\cdot))\le 0,\ =0 \text{ if } \mu_t>0, \tag{20}$$

$$\Omega^*(s_t,\tau_t,\tau_t^*)-\frac{\beta}{1-\beta}\omega^*(\tau_c(\cdot),\tau_c^*(\cdot))\le 0,\ =0 \text{ if } \mu_t^*>0. \tag{21}$$

The first-order conditions characterize the trade policies τ_t and τ_t^* only as functions of the cooperative trade policy functions $\tau_c(\cdot)$ and $\tau_c^*(\cdot)$ which define the expected future welfare gains from cooperation in equations (20) and (21). The most cooperative subgame perfect trade policies are those that for every t satisfy the first-order conditions (18)–(21) and

$$\tau_t = \tau_c(s_t) \text{ and } \tau_t^* = \tau_c^*(s_t). \quad (22)$$

Equation (22) enforces rational expectations about future periods by ensuring that the applied trade policies derive from the same policy functions that will be applied subsequently.

When the discount factor falls below $\overline{\beta}$, given that Nash trade policies and best-response functions present several kinks, and that policies may occasionally be constrained to be taxes, a complete analytical characterization of the policies, including a proof of their existence, is out of reach.[6] Below, we provide an interpretation of these equations in various situations depending on which constraint is binding, and we later rely on numerical simulations to provide further insights on the solution.

The first-order conditions can be interpreted as follows. μ and μ^* play the role of the relative weighting of countries in world welfare. It may change at each period depending on which participation constraint is binding. When one country's participation constraint is binding, its welfare weight becomes positive justifying its deviation from the first-best trade policy (i.e., from free trade).

No binding participation constraint With $\mu_t = \mu_t^* = 0$, equations (18) and (19) are identical to what they would be were the maximization not subject to the participation constraints, that is to globally efficient trade policies. Equation (18) gives $\tau_t^* - \tau_t \leq 0$, $= 0$ if $\tau_t \leq 0$, which is only compatible with $\tau_t = \tau_t^* = 0$. Thus, when no participation constraint is binding, the cooperative policy is free trade. Note, however, that this is a consequence of restricting the analysis to tax policies. Without this restriction, the solution would be $\tau_t = \tau_t^*$, which is compatible with free trade and also with countercyclical trade policies that perfectly offset each other.

Binding participation constraints For a discount factor below $\overline{\beta}$, the efficient trade policy does not satisfy the participation constraints for all possible shocks, so the cooperative trade policies must include some deviation from free trade. These deviations from free trade are governed in the first-order conditions by the Lagrange multipliers that play the role of state-contingent welfare weights: they ensure that trade policies always satisfy the participation constraints. There are three possible situations: participation constraint binding for Home, for Foreign, or for both countries. This contrasts with Bagwell and Staiger (1990) where the situation of both participation constraints binding was the only possible one, because the only motivation for trade policies was the terms-of-trade gains which similarly affect the temptation to deviate in the two countries. In this paper, we also have the smoothing motivation which has asymmetric effects.

[6] See Bagwell and Staiger (1990) for the analytical characterization of a similar but simpler problem.

The temptation to deviate will be higher for exporters in periods of high prices and for importers in periods of low prices.

If both welfare weights are strictly positive, the terms $\partial W_D^*(s_t,\tau_t)/\partial\tau_t$ and $\partial W_D(s_t,\tau_t^*)/\partial\tau_t^*$ in equations (18) and (19) may matter. They account for the fact that when a country changes its trade policy, this changes its partner's incentives to deviate. This concern about the partner's incentive to deviate exists only if the partner's participation constraint is binding. If not, the country does not have to worry about its partner's incentive until it becomes binding. Given the behavior in Nash, in cooperation, we could expect the participation constraints to be both binding for intermediate free-trade price levels and a sufficiently high free-trade trade volume. For a high (low) free-trade price, the deviation will come from the exporter (importer). For an intermediate price level, this is the terms-of-trade motivation that will compel both countries to deviate at the same time (as in Bagwell and Staiger, 1990).

5. Numerical simulations

In this section, we analyze cooperative behavior further by conducting numerical simulations. Given the absence of endogenous state variables, it is easy to calculate a numerical solution to this problem. It is the solution to a set of complementarity equations defined over a grid of carefully chosen production shocks (through a Gaussian quadrature) which will allow us to calculate the terms in expectations. The equations are the first-order conditions, (18)–(21), and the equations ensuring that the same cooperative trade policies are applied in subsequent periods (i.e., expectations are rational), (22). See the appendix for details of the numerical methods.

We focus the discussion of numerical results on the situation of pure aggregate risk, in which the smoothing motivation for trade intervention is dominant. Since in this case free-trade price summarizes the state of the system, this facilitates the interpretation of results by allowing diagrammatic representations. In the alternative configuration of pure idiosyncratic risk, the results are very close to Bagwell and Staiger (1990), the only difference being that our static level of protection is less important because the smoothing objective goes against the exploitation of terms-of-trade gains. In that case, trade policies are of equal intensity but with opposite signs. In a repeated game, for a sufficiently high discount factor, the threat of retaliations allows coordination on free trade. For a lower discount factor, deviations from free trade cannot be excluded. They occur at the same moment for both countries – when free-trade volume is high, because a higher free-trade volume increases the potential terms-of-trade gains and the incentive to deviate.

To choose relevant values for K, the parameter of preference for price stability, we note that although the quadratic term in the social welfare functions is merely a means of introducing (in a tractable way) additional concavity into the social welfare function, it can also be given some micro-foundations by being interpreted as the difference between the second-order approximation to the equivalent variation of a risk-averse consumers and its surplus, so it would be the welfare term accounting for non-zero risk aversion and income elasticity. Following Turnovsky et al. (1980), K would in this case be equal to $\gamma(R-\nu)D(\bar{P})/\bar{P}$, where γ, R, and ν are values at steady-state of the commodity budget share, relative risk aversion to income, 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-markets economy in which risk-averse consumers cannot insure against food price risk (see Gouel and Jean, forthcoming, for such a situation). We assume $K=0.3$, which could correspond to a 15% budget share, a relative risk aversion equal to 2, and a null income elasticity.

The other parameters are chosen such that at steady state in both countries demand is equal to 1 and trade to 0.2. The steady-state price is taken to be 1 and demand elasticity -0.2. In what follows, results will differ in the assumed distributions for the production shocks. Production shocks are assumed to be either symmetric or skewed. Since we focus on a situation of aggregate risk where V^f is constant, ε^* is defined from ε and is equal to $\varepsilon-0.4$. ε is assumed to follow a beta distribution. The distribution is translated and rescaled for ε to have a mean of 1.2 and a standard deviation of 0.06. With this choice of parameters and distribution of production shocks, the coefficient of variation of the free-trade price is equal to 30%. For the symmetric case, the beta distribution has shape parameters 3 and 3. For the asymmetric cases, the second parameter is maintained at 3, while the first is adjusted to change the skewness (the location and scale parameters are also adjusted to maintain the mean and standard deviation constant).

5.1. Cooperation under a symmetric price distribution

This example illustrates the extent of trade policy coordination when the free-trade price distribution is symmetric around the steady-state price. Figure 2 displays the cooperative and non-cooperative trade policies for various discount factors. At a distance of the steady-state price, the non-cooperative Nash policies (dash-dotted curves) are constrained by their restriction to being taxes. For high world prices, the importing country would like to apply an import subsidy. When this constraint binds, the slope of the exporting country trade policy decreases with respect to the world price, because it does not need to react so strongly to the world price since its policy is no longer offset by its partner. This change in slope when only one country is using its trade policy occurs in repeated games also.

When the game is repeated, policies that are more cooperative are sustainable, although it is not possible always to exclude deviations from free trade for high and low free-trade prices. Cooperative policies are represented in figure 2 for various discount factors, in solid lines. There are three possible regimes. (i) For a sufficiently high discount factor, $\beta \geq \bar{\beta} = 0.80$, free trade can be sustained by the threat of retaliation whatever the level of stochastic shocks. (ii) For a lower value of the discount factor, participation constraints start to bind for low and high world prices. However, they are not binding at the same time; each country is allowed to deviate from free trade at different moments. The exporter deviates when the world price is high by taxing

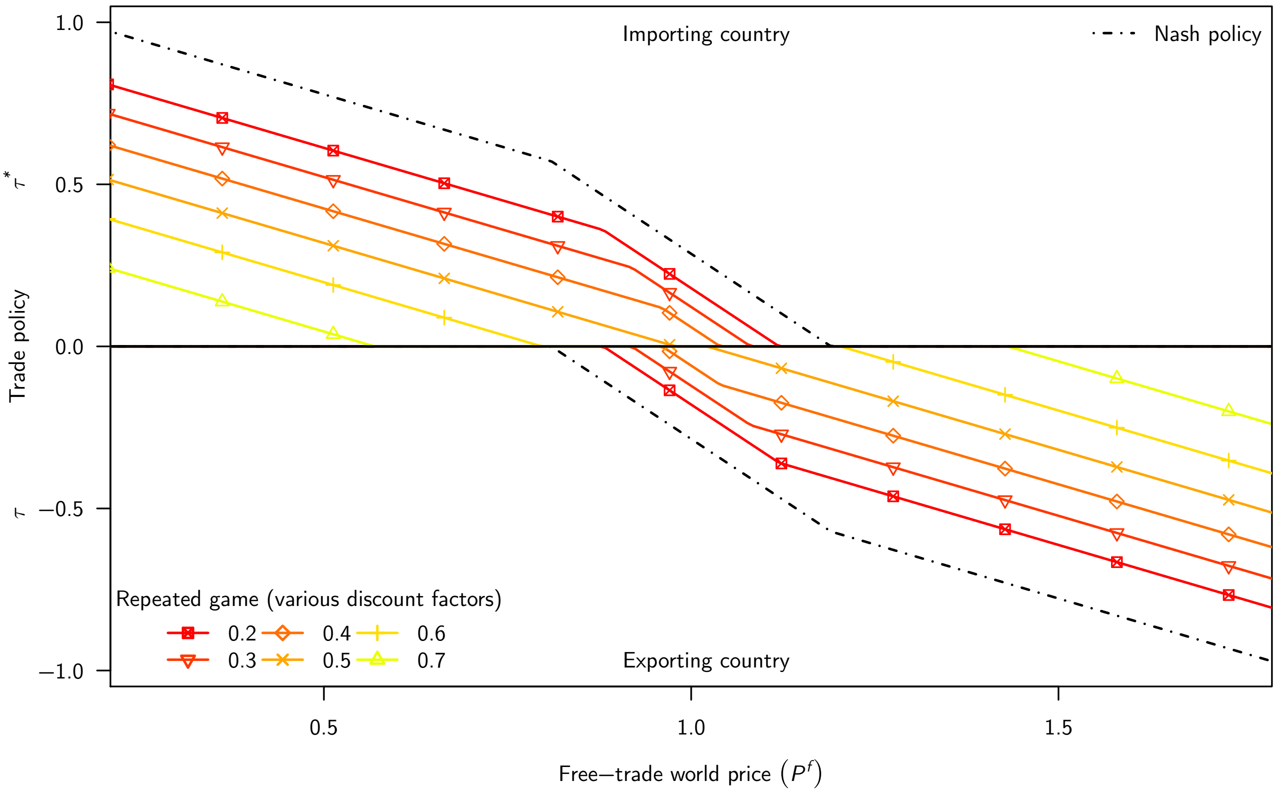

Figure 2 – Cooperative and non-cooperative trade policies under a symmetric price distribution

exports, and the importer deviates when the world price is low by taxing imports. Outside the regions where participation constraints are binding, the cooperative trade policy is free trade. These trade policies affect the distribution of world price with respect to free trade. The world price will be identical to the free-trade price when this latter is close to the steady state. But far from the steady state, when the incentives to deviate from free trade are too high to make it sustainable in cooperation, the world price will be above (below) the free-trade price if the free-trade price is above (below) its steady state. Cooperation reduces the volatility of world price, but mainly close to steady state, and less for low and high world prices. (iii) For lower values of the discount factor, participation constraints bind more often, and can be binding at the same time. This situation is qualitatively closer to the Nash situation than the two others. Note that the discount factor should be interpreted not as a market discount factor but as the discount factor of policy-makers for which the future may not extend much farther than the next election.

5.2. Cooperation under an asymmetric price distribution

Some of the previous results are a consequence of the symmetry of the problem. Beyond the perfect symmetry of the countries, what seems crucial is the symmetry of the price distribution, which itself is an outcome of many assumptions. In reality, commodity prices are positively skewed (Deaton and Laroque, 1992), a feature often explained by storage, which would have been too challenging to integrate in a repeated-game approach. Price skewness can also be explained in other ways. A convex demand function, for example, could create skewness in the price distribution. This is precisely the effect of storage, which convexifies demand by adding to final demand, demand for stocks at low prices (Wright and Williams, 1982). Positive price skewness could also arise from a negatively skewed yield.

The lack of symmetry of the price distribution could be crucial because it affects the distribution of welfare between the two countries, and consequently, what could be expected from cooperation ensured by the threat of retaliation. To analyze this we introduce an asymmetry by assuming that yields are negatively skewed. This does not involve any change in the equations. They hold equally for symmetric and asymmetric shocks. Results will be symmetric with positively-skewed yields; but negatively-skewed yields imply positively-skewed prices, as observed in the price data. Below, ε is assumed to follow a beta distribution with shape parameters 30 and 3 which results in a skewness of the free-trade price equal to 0.95, a value comparable to that observed for staple food markets (Deaton and Laroque, 1992).

The asymmetry affects the respective costs of the trade war between the exporting and the importing countries. In the static game (0 discount factor in figure 3), the interior Nash equilibrium is more costly for the exporting than the importing country. This is explained by the price distribution (see figure 4). Upward price spikes are more common than downward price spikes, so we more often observe large trade policy interventions from the exporter compared to the importer. However, much of the price distribution is concentrated in prices below the target price, with a significant share in the region where the exporting country does not apply export restrictions. So, on average, the exporting country suffers more from the trade war, because it is more often constrained in its trade policies.

In a repeated game, these lower losses for the importing country hold for a low to medium discount factor (until $\beta \approx 0.51$), because cooperation does not change the fact that the exporting country is more often constrained in its trade policies. However, the relationship between the discount factor and the difference between expected welfare under coordination and under free trade is not monotonic. For a high enough discount factor, neither country uses trade policies and their welfare is equal to the free-trade value. However, before reaching the first-best welfare there is an interval over the discount factor for which exporting country welfare exceeds free-trade welfare and most of the welfare increases are captured by the exporting country. For these intermediate discount factor values, the threat of reverting to a trade war exceeds the short-run gains from deviation for most of the free-trade world price, and free trade prevails for most supply shocks. In particular, for the importing country, the gains from deviation are never very high since the free-trade world price does not reach very low values. On the contrary, for the exporting country, the gains from deviation can occasionally be high because of the possibility of high world prices. In these cases, when the discount factor is not too high, the participation constraint of the exporter is binding and compels it to deviate from the first best. This situation

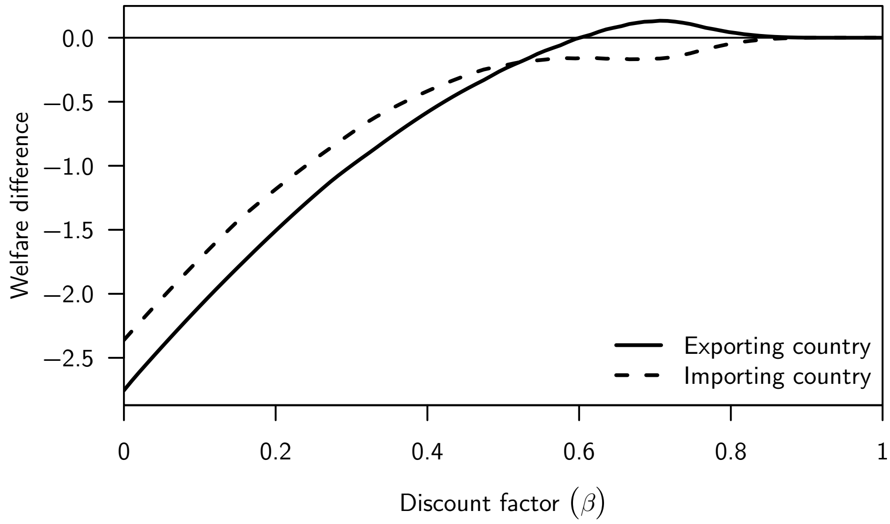

Figure 3 – Difference between expected welfare under coordination and free trade under an asymmetric price distribution, $\mathrm{E}_s[W(s,\tau_c(s),\tau_c^*(s)) - W(s,0,0)]$ (as a percentage of the steady-state budget spent by consumers on this commodity)

is asymmetrical as shown in figure 4 when $\beta = 0.8$: the discount factor is high enough to deter any deviation from first best for the importer, but not sufficiently high for the exporter given that the price distribution is skewed. Since the exporter occasionally applies trade policies, while the importer does not, the former enjoys a welfare level above what it could achieve from free trade at the expense of its partner. Despite the exporting country being the country with more to gain from cooperation since it suffers more in the interior Nash equilibrium, it is also the more reluctant to cooperate given that the occasional price spikes compel it to maintain some deviation from free trade.

The role of price skewness can also be analyzed in relation to its effect on the threshold discount factor. The threshold discount factor above which free trade can be sustained in cooperation is defined (equation (16)) as the maximum between the discount factor that makes the participation constraint of the exporting country hold with an equality at the highest price, and the discount factor that makes the participation constraint of the importing country hold with an equality at the lowest price. For a symmetric price distribution, these two parameters are identical but if the distribution becomes positively skewed, they will start to differ (figure 5). The threshold discount factor corresponding to the exporting country increases with price skewness as the maximum price gets further away from the target price. The threshold discount factor corresponding to the importing country decreases with price skewness as the minimum price gets closer to the target. This behavior holds if, instead of using the discount factor sustaining free trade in all states, we use the discount factor sustaining free trade in all states except the 1% lowest and highest prices. So, in this setting where production shocks are governed by a beta distribution, increasing skewness while keeping the first two moments constant makes free trade more difficult

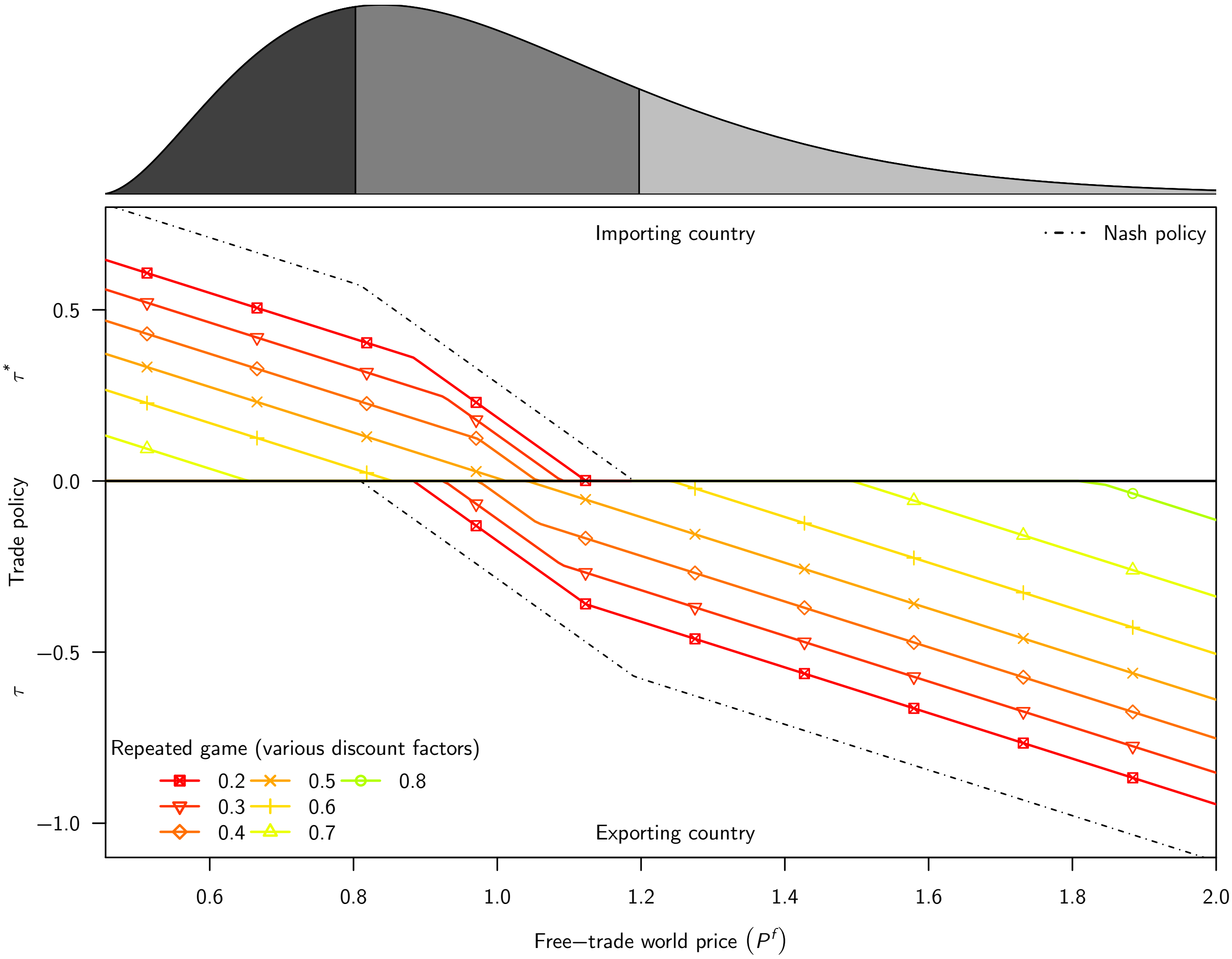

Figure 4 – Trade policies under asymmetric price distribution. Density of free-trade world price above the plot, with a distinction between the regions where, in the Nash, only the importing country intervenes, where countries both intervene, and where only the exporting country intervenes.

to sustain in cooperation, because of the asymmetry in the short-run incentives of the exporter and the importer to deviate.

6. Conclusion

Considering that governments care about domestic food price volatility and use trade policy instruments to stabilize their food markets, this paper analyzes the extent of international trade policy cooperation that is enforced by the threat of a return to the static interior Nash equilibrium. The present analysis differs from the related literature (Bagwell and Staiger, 1990, 2003) by considering that governments adjust trade policy in order to manipulate their terms of trade and also to stabilize their domestic food prices. It stresses the important distinctions between

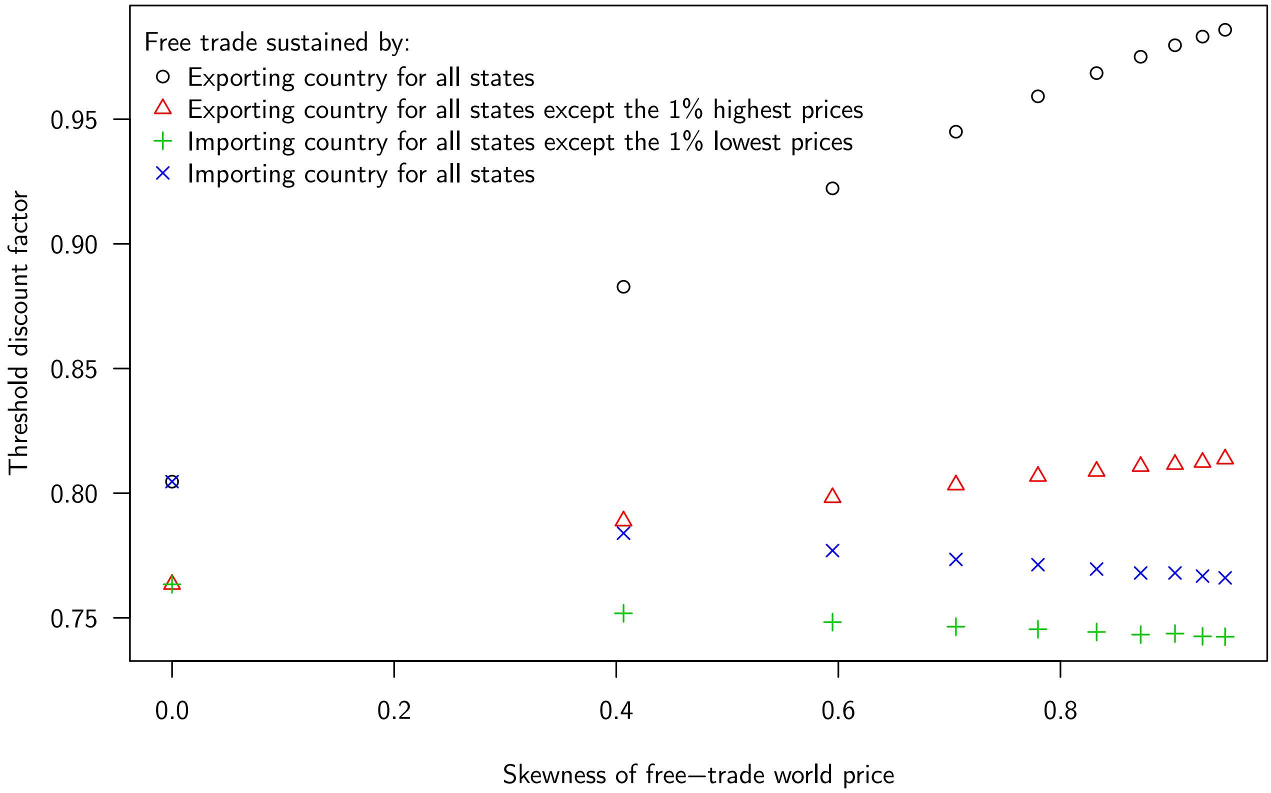

Figure 5 – Threshold discount factors sustaining free trade for various levels of price skewness. Price skewness is adjusted by increasing the first shape parameter in the beta distribution of ε by increment of 3.

aggregate and idiosyncratic supply shocks for trade policy interventions. The terms-of-trade motivation is related only to idiosyncratic shocks (i.e., shocks to free-trade trade volumes) and does not lead to any trade policy adjustments in the case of aggregate shocks (i.e., shocks to the free-trade world price), which are an important driver of actual trade policy adjustments for food products (Anderson and Nelgen, 2012). On the contrary, the smoothing motivation is related only to aggregate shocks and would not hinder the risk sharing of idiosyncratic supply shocks.

This work demonstrates a standard feature of self-enforcing trade agreements: the need for active trade policies in periods of severe shocks to maintain the incentives to cooperate in every state of nature. While repeated interactions allow countries to coordinate on cooperative trade policies, periods of unusually high trade volume, or very low or very high prices, are periods of deviation from free trade. So even in a cooperative agreement, it may not be possible to completely alleviate countercyclical trade policies. These deviations from first best differ from the previous literature in that, because of the smoothing motivation deviations are asymmetric: exporters deviate when the world price is high and importers deviate when the world price is low.

Policy discussions have devoted a lot of attention to export restrictions and their role in recent food price spikes. To prevent future price spikes, many authors have advocated the adoption of WTO disciplines on export restrictions, which currently are very weakly regulated. In this paper, export restrictions are no more important than tariffs. The former are the policy used by exporters to protect themselves from international scarcity, and the latter are the policy used by importers, but both contribute to shift volatility to partners' markets.

However, despite this apparent symmetry between trade policy instruments, export restrictions under repeated interactions may be more difficult to avoid than tariffs because of the asymmetry of the price distribution. Commodity prices are positively skewed and prices are concentrated below the mean, but with occasional spikes. This matters a lot in self-enforcing agreements because it means that the exporter will have a bigger incentive to deviate from free trade than the importer. In this light, export restrictions may be more difficult to discipline in trade agreements than tariffs, and the reluctance of food exporting countries to open negotiations on this issue may be a sign of their inability to commit to not using export restrictions given the incentives they are offered during food price spikes.

Appendix

This appendix gathers all the equations that define the cooperative policies and describes how the model is solved numerically. Since all the variables on the interior Nash equilibrium are characterized analytically by equations (1), (5)–(6), and (10)–(12), this appendix focuses on the dynamic game. The problem is implemented numerically in GAMS version 23.9.5 and solved on a PC running Windows 7 using the mixed complementarity solver PATH (Dirkse and Ferris, 1995), with a precision of 10^{-7}.[7] Since the model has no intrinsic dynamics, there is no need to consider several periods. However, the model has to be solved over various supply shocks to allow for the calculation of expectations. The shocks on which the model is solved are chosen through 55-node Gaussian quadratures,[8] which define sets of pairs $\{(\varepsilon_i, \varepsilon_i^*), w_i\}$ in which $(\varepsilon_i, \varepsilon_i^*)$ represents a possible realization of shocks and w_i the associated probability. In the following, except for the time index which is substituted by i or j, the mathematical notations mostly follow the paper. i and j index possible shocks realizations. The superscript D is used to designate situations of deviation from the cooperative policies.

The expected welfare under Nash ($\mathrm{E}W_N$ and $\mathrm{E}W_N^*$) is calculated by replacing the expectations operators by sums using the Gaussian quadrature and using the analytical expressions of welfare, (5) and (6), and Nash trade policies, (10) and (11). Other variables solve the following set of complementarity equations, in which for compactness some functions are introduced and defined later:[9]

$$P_i^f : P_i^f = \frac{a}{b} - \frac{\varepsilon_i + \varepsilon_i^*}{2b}, \tag{23}$$

$$V_i^f : V_i^f = \frac{\varepsilon_i - \varepsilon_i^*}{2}, \tag{24}$$

$$P_i^w : P_i^w = P_i^f - \frac{\tau_i + \tau_i^*}{2}, \tag{25}$$

$$P_i : P_i = P_i^w + \tau_i, \tag{26}$$

$$P_i^* : P_i^* = P_i^w + \tau_i^*, \tag{27}$$

$$W_i : W_i = \int_{P_i}^{a/b} D(p)\,\mathrm{d}p + P_i\varepsilon_i - \tau_i\left[\varepsilon_i - D(P_i)\right] - K\frac{(P_i - \bar{P})^2}{2}, \tag{28}$$

$$W_i^* : W_i^* = \int_{P_i^*}^{a/b} D^*(p)\,\mathrm{d}p + P_i^*\varepsilon_i^* - \tau_i^*\left[\varepsilon_i^* - D^*(P_i^*)\right] - K\frac{(P_i^* - \bar{P})^2}{2}, \tag{29}$$

$$\tau_i : \tau_i \le 0 \perp (1+\mu_i)\frac{\partial W(s_i, \tau_i, \tau_i^*)}{\partial \tau_i} + (1+\mu_i^*)\frac{\partial W^*(s_i, \tau_i, \tau_i^*)}{\partial \tau_i} \ge \mu_i^* \frac{\partial W_D^*(s_i, \tau_i)}{\partial \tau_i}, \tag{30}$$

[7] Programs are available from the author upon request.

[8] Gaussian quadrature are generated using the functions available in the MATLAB toolbox CompEcon (Miranda and Fackler, 2002).

[9] Complementarity conditions in what follows are written using the "perp" notation ($\perp$). This means that both inequalities must hold, and at least one must hold with equality.

$$\tau_i^*: \tau_i^* \geq 0 \perp (1+\mu_i^*)\frac{\partial W^*(s_i,\tau_i,\tau_i^*)}{\partial \tau_i^*} + (1+\mu_i)\frac{\partial W(s_i,\tau_i,\tau_i^*)}{\partial \tau_i^*} \leq \mu_i \frac{\partial W_D(s_i,\tau_i^*)}{\partial \tau_i^*}, \tag{31}$$

$$\mu_i: \mu_i \geq 0 \perp W_i + \frac{\beta}{1-\beta}\sum_j w_j W_j \geq W_i^D + \frac{\beta}{1-\beta}\mathrm{E}W_N, \tag{32}$$

$$\mu_i^*: \mu_i^* \geq 0 \perp W_i^* + \frac{\beta}{1-\beta}\sum_j w_j W_j^* \geq W_i^{*D} + \frac{\beta}{1-\beta}\mathrm{E}W_N^*, \tag{33}$$

$$W_i^D: W_i^D = \int_{P_i^D}^{a/b} D(p)\,\mathrm{d}p + P_i^D\varepsilon_i - \tau_i^D\left[\varepsilon_i - D\left(P_i^D\right)\right] - K\frac{\left(P_i^D-\bar{P}\right)^2}{2}, \tag{34}$$

$$W_i^{*D}: W_i^{*D} = \int_{P_i^{*D}}^{a/b} D^*(p)\,\mathrm{d}p + P_i^{*D}\varepsilon_i^* - \tau_i^{*D}\left[\varepsilon_i^* - D^*\left(P_i^{*D}\right)\right] - K\frac{\left(P_i^{*D}-\bar{P}\right)^2}{2}, \tag{35}$$

$$\tau_i^D: \tau_i^D \leq 0 \perp \tau_i^D \leq 2\frac{K\left(\bar{P}-P_i^f\right)-V_i^f}{K+3b} + \frac{K+b}{K+3b}\tau_i^*, \tag{36}$$

$$\tau_i^{*D}: \tau_i^{*D} \geq 0 \perp \tau_i^{*D} \geq 2\frac{K\left(\bar{P}-P_i^f\right)+V_i^f}{K+3b} + \frac{K+b}{K+3b}\tau_i, \tag{37}$$

$$P_i^D: P_i^D = P_i^{wD} + \tau_i^D, \tag{38}$$

$$P_i^{*D}: P_i^{*D} = P_i^{w*D} + \tau_i^{*D}, \tag{39}$$

$$P_i^{wD}: P_i^{wD} = P_i^f - \frac{\tau_i^D+\tau_i^*}{2}, \tag{40}$$

$$P_i^{w*D}: P_i^{w*D} = P_i^f - \frac{\tau_i+\tau_i^{*D}}{2}. \tag{41}$$

From equations (5) and (6), we have

$$\frac{\partial W(s_i,\tau_i,\tau_i^*)}{\partial \tau_i} = \frac{-K(P_i-\bar{P}) - b(P_i-P_i^w) - \varepsilon_i + D(P_i)}{2}, \tag{42}$$

$$\frac{\partial W^*(s_i,\tau_i,\tau_i^*)}{\partial \tau_i} = \frac{K(P_i^*-\bar{P}) + b(P_i^*-P_i^w) - \varepsilon_i^* + D^*(P_i^*)}{2}, \tag{43}$$

$$\frac{\partial W(s_i,\tau_i,\tau_i^*)}{\partial \tau_i^*} = \frac{K(P_i-\bar{P}) + b(P_i-P_i^w) - \varepsilon_i + D(P_i)}{2}, \tag{44}$$

$$\frac{\partial W^*(s_i,\tau_i,\tau_i^*)}{\partial \tau_i^*} = \frac{-K(P_i^*-\bar{P}) - b(P_i^*-P_i^w) - \varepsilon_i^* + D^*(P_i^*)}{2}. \tag{45}$$

Using the envelop theorem

$$\frac{\partial W_D^*(s_i,\tau_i)}{\partial \tau_i} = \frac{\partial W^*(s_i,\tau_i,\tau_R^*(s_i,\tau_i))}{\partial \tau_i}, \tag{46}$$

$$= \frac{K\left(P_i^{*D}-\bar{P}\right) + b\left(P_i^{*D}-P_i^{w*D}\right) - \varepsilon_i^* + D^*\left(P_i^{*D}\right)}{2}, \tag{47}$$

and similarly

$$\frac{\partial W_D\left(s_i,\tau_i^*\right)}{\partial \tau_i^*}=\frac{K\left(P_i^D-\bar{P}\right)+b\left(P_i^D-P_i^{wD}\right)-\varepsilon_i+D\left(P_i^D\right)}{2}. \tag{48}$$

The expectations of welfare under cooperation should be consistent with the cooperative trade policies actually chosen. This is ensured numerically by equations (32) and (33), where the expressions $\sum_j w_j W_j$ and $\sum_j w_j W_j^*$ represent the welfare expectations discretized by the Gaussian quadrature. So in the solution process the expectations change endogenously with the cooperative trade policies.

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