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Effects of Sustainable Regulations at Agricultural International Market Failures: A Dynamic Approach

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Abstract: Several policies have been proposed to reduce the environmental impact of agricultural trade. However, a number of these policies have low efficiency on a global scale due to side effects on third-competitor countries. The objective of this article is to assess the consequences of these policies under the existence of market failures that characterise the agricultural sector (i.e., ex ante price uncertainty and oligopoly in international markets). In particular, it is shown that some of these policies could cause instability in the agricultural trade system in the short/medium run, as well as permanent adverse side effects on competitor countries. Using a theoretical dynamic model that includes these failures, it was found that instability could be reduced by supplying information that could help producers to improve price forecasting. Likewise, the adverse side effects could be prevented by means of sustainable policies adopted co-ordinately by competitor countries. This latter result is consistent with the general strategies stated by the Climate Club.

Keywords: agricultural trade; agricultural emissions; sustainable policies; market failures

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1. Introduction

Air pollution from the agricultural activity is a well-known fact that has attracted the attention of academics and policymakers over the last few decades. According to Lewis et al. [1], the main compounds emitted from agricultural activities to the atmosphere with potential human health effects are nitrogen-containing ones, with ammonia and nitrous oxide as the main contributors. Agriculture also emits carbon dioxide and methane, contributing to the global anthropogenic greenhouse gas emissions (GHGs) by approximately 10–13% [2–4]. However, in some regions of the world, such as East Africa, agriculture contributes to greenhouse gas emissions by 34%, and this is explained by a general increase in food demand, intensification of agricultural production, adoption of more synthetic fertilizers and the expansion of agricultural lands [5].

The adverse effects of agricultural emissions on the environment and human health have led to several potential mitigating strategies, such as improved feed quality, improved manure management, greater nitrogen use efficiency, better water management, conservation practices that help prevent soil erosion, manipulating animal diets, input and output constraints, removing subsidies to agriculture, adoption of environmental tax policies and increasing the role of agroforestry in agriculture, among others [6–10]. As a consequence of these strategies and policy intervention, a substantial decrease in emissions has been observed in Europe since 1990. However, agricultural emissions in Africa, Latin America, Central America and Asia have increased significantly [11]. This suggests that the proposed mitigating strategies may not have been fully adopted in these regions, or perhaps they have not been fully effective in addressing the increase in food demand and intensification of agricultural production.

This may also be related to the connection between international trade and the environment. In this regard, efforts to promote environmental sustainability in developed countries can take place at the cost of increasing land displacement elsewhere to meet their demand and the demand from foreign countries through exports of agricultural goods [12]. Given this possibility, several academic works have been developed to explore the link between international trade and emissions. However, most of them are not sector-specific, suggesting that the effects of agricultural trade on agricultural emissions need to be better understood. In this respect, Balogh and Jámbor [13] developed a systematic literature review to explore what is known about the environmental impacts of agricultural trade. The results revealed that most of the revised articles have found that agricultural trade harms the environment, mainly in terms of greenhouse gas emissions. This is, without a doubt, an important finding. However, most of these academic articles empirically explain the environmental trade impact but not necessarily the economic mechanism behind this evidence [14–16]. An exception is a work by Lapan and Sikdar [17], who developed a general theoretical model based on oligopoly, but with the potential to be applied to some agricultural commodities, according to the authors. Using this theoretical framework, the authors explored different environmental strategies to reduce emission in the context of international trade.

In considering these studies, it was found that a relevant knowledge gap in this research area is a lack of understanding of the economic mechanism that links agricultural trade and the environment under the presence of market failure. In considering this gap, the objective of this article is to is to assess the consequences of environmental policies under the existence of market failures that characterise the agricultural sector by explaining, theoretically, the mechanism by which agricultural trade affects agricultural emissions. However, in contrast to the work by Lapan and Sikdar [17], the current article analyses this issue from the point of two market failures that are present in a number of agricultural and food-processed goods traded internationally. First, farmers are exposed to ex ante price uncertainty because of both the delay between the establishment of an agricultural good and the period when it is ready for selling purposes and the global phenomenon of price volatility [18–20]. While several strategies have been introduced to help farmers to cope with the price risk, such as market contracts, they have yet to be widely adopted, implying that this imperfection still affects farmer decision-making [21]. Second, several international agricultural and food-goods markets operate under oligopolies. It is argued that this type of failure arises from the high concentration of intermediaries in the food industry [22–24].

When these two types of market failures were included into the analysis, a dynamic framework was obtained. Using this framework, it was found that the trade system becomes unstable when farmers face ex ante price uncertainty. That is, shocks that affect the trade system cause short/medium-term emission fluctuations in the competitor countries that dissipate in the long run when markets return to the long-run equilibrium. In this context, environmental policies can be considered shocks that create initial instability in the trade system, until a new long-run equilibrium is reached. The speed of adjustment will depend on how farmers form their expectations about future prices for their production, suggesting that the beneficial impacts of environmental policies may be perceived in the long run when instability disappears. It was also found that when a country adopts environmental policies unilaterally, adverse emission side effects could be transmitted to other competitive countries. This suggests that when these market failures are present, sustainable environmental policies should be implemented simultaneously by competitor countries with strategies that can reduce farmer price uncertainty. This result is consistent with the general strategies of the Climate Club. According to Stern and Lankes [25], this club, called by the G7 leaders, was created to deal with the current challenges of climate change and is centred on the Paris and Glasgow goals. The aim of this club is to develop transparent climate mitigation policies to reduce emissions by means of a coordinated and collaborative approach among countries representing a large proportion of global greenhouse gas emissions. The results obtained in the current research provide specific sectorial policy strategies that are aligned to the general focus of the Climate Club and could be considered as useful guidelines for emission policies in the agricultural sector.

It is important to highlight that those trade models assuming oligopoly have also been adopted to explore the impact of both trade and environmental policies on the environment [26–28]. However, they are not sector specific; they are static and do not consider the ex-price risk that characterises the agricultural sector. Therefore, our contribution to this research field is introducing of ex-price risk into a dynamic oligopolistic framework. This risk corresponds to price forecasting errors by producers with imperfect information that compromise the profits made by the competitor countries and is captured by a proposed forecasting rule that is based on a form of adaptive expectations (i.e., farmers consider a weighted average of actual and possible future production by the competitor players in the market).

The article is organised as follows: Section 2 presents the theoretical model developed in this research. Section 3 shows and discusses the results. Finally, Section 4 concludes with the main findings.

2. The Theoretical Model

The model assumes the existence of two countries, referred to as i and j, competing Cournot in a third country, k. Let q^i and q^j be the agricultural good produced in countries i and j, respectively, and let c_i and c_j be the marginal cost faced by the producers in these countries. An important aspect that producers have to consider when planning the quantity to be produced is the period of time between establishing the agricultural good and harvesting. This means that producers determine the current output (i.e., period t) by considering the possible price they will receive in the next period $t + 1$ (assuming that farmers do not use market contracts, which is what is observed in several countries as pointed out by Michels et al. [21]). This is modelled assuming that producers in countries i and j maximise, respectively, the following expected profit functions:

$$E_t^i\left(\pi_{t+1}^i\right) = \left(E_t^i\left(P_{t+1}^k\right) - c_i\right)q_{t+1}^i \quad (1)$$

$$E_t^j\left(\pi_{t+1}^j\right) = \left(E_t^j\left(P_{t+1}^k\right) - c_j\right)q_{t+1}^j \quad (2)$$

where $E_t^i(\pi_{t+1}^i)$ is the expectation in period t of the profit that the producer in country i will make in the next period $t + 1$ (the same meaning applies to $E_t^j\left(\pi_{t+1}^j\right)$ but for country j); and P_{t+1}^k is the price that producers in countries i and j will obtain in country k when selling their output in the next period $t + 1$. This price is determined by the following inverse demand function in country k:

$$P_{t+1}^k = \alpha - q_{t+1}^i - q_{t+1}^j \quad (3)$$

Because this price is unknown in period t, it is assumed that the producers in countries i and j form an expectation about this price according to the following expressions:

$$E_t^i\left(P_{t+1}^k\right) = \alpha - q_{t+1}^i - E_t^i\left(q_{t+1}^j\right) \quad (4)$$

$$E_t^j\left(P_{t+1}^k\right) = \alpha - E_t^j\left(q_{t+1}^i\right) - q_{t+1}^j \quad (5)$$

According to these expressions, the expected price from the point of view of the producer of a determined country is determined by the expected production of the competitor country. This expectation is modelled as follows:

$$E_t^i\left(q_{t+1}^j\right) = \lambda q_t^j + (1-\lambda)q_{t+1}^j \quad (6)$$

$$E_t^j\left(q_{t+1}^i\right) = \gamma q_t^i + (1-\gamma)q_{t+1}^i \tag{7}$$

where $\lambda \in [0,1]$ and $\gamma \in [0,1]$ are parameters. According to these equations, the expected value of the future output produced by the competitor is defined as a weighted average between the output produced by the competitor in period t and in period $t + 1$. To understand how this expectation process works, consider Equation (6) (the same explanation applies to Equation (7)). If the future output produced by the competitor in country j is completely unknown, then $\lambda = 1$. That is, the producer in country i uses the output produced by the competitor in the current period t as a proxy of the output that will be produced in the next period $t + 1$. That is, $E_t^i\left(q_{t+1}^j\right) = q_t^j$. In contrast, if the producer in country i can anticipate with certainty the output that will be produced by the competitor in period $t + 1$, then $\lambda = 0$ and $E_t^i\left(q_{t+1}^j\right) = q_{t+1}^j$. That means that, in this case, the producer in country i has a perfect forecast. Finally, if $0 < \lambda < 1$, then the producer in country i has partial information about the future production of country j and bases his/her expectation considering this partial information and the current output produced by the competitor.

Using Equations (1), (4) and (6), the expected profit for the producer in country i becomes:

$$E_t^i\left(\pi_{t+1}^i\right) = \left(\alpha - c_i - q_{t+1}^i - \lambda q_t^j - (1-\lambda)q_{t+1}^j\right)q_{t+1}^i \tag{8}$$

The first-order condition when maximising this expression leads to the following reaction function for country i:

$$q_{t+1}^i = \frac{\alpha - c_i}{2} - \frac{\lambda q_t^j}{2} - \frac{(1-\lambda)q_{t+1}^j}{2} \tag{9}$$

Similarly, the reaction function for country j is given by:

$$q_{t+1}^j = \frac{\alpha - c_j}{2} - \frac{\gamma q_t^i}{2} - \frac{(1-\gamma)q_{t+1}^i}{2} \tag{10}$$

By replacing Equations (9) and (10), the following equation in difference for country i is obtained:

$$q_{t+1}^i = \frac{\alpha - c_i}{4-(1-\lambda)(1-\gamma)} + \frac{(1-\lambda)\gamma + (1-\gamma)\lambda}{4-(1-\lambda)(1-\gamma)}q_t^i + \frac{\lambda\gamma}{4-(1-\lambda)(1-\gamma)}q_{t-1}^i \tag{11}$$

The solution for this equation is (a similar expression can be obtained for country j):

$$q_t^i = \left(\frac{1-b_2}{b_1-b_2}\right)\left[q_0^i - q^{iN}\right]b_1^t + \left(\frac{1-b_1}{b_1-b_2}\right)\left[q^{iN} - q_0^i\right]b_2^t + q^{iN} \tag{12}$$

where $q^{iN} = \frac{\alpha - 2c_i + c_j}{3}$ is the Nash equilibrium of steady state; q_0^i is the initial condition, defined as the output produced in country i in period 0; $b_1 = \frac{\phi_1 + \sqrt{\phi_1^2 + 4\phi_2}}{2}$; $b_2 = \frac{\phi_1 - \sqrt{\phi_1^2 + 4\phi_2}}{2}$; $\phi_1 = \frac{(1-\lambda)\gamma + (1-\gamma)\lambda}{4-(1-\lambda)(1-\gamma)}$; and $\phi_2 = \frac{\lambda\gamma}{4-(1-\lambda)(1-\gamma)}$.

Let us now link this dynamic model to the issue of emission. For simplicity, it will be assumed that emission, e, is proportional to the produced output. That is, $e_t^i = q_t^i$ in country i and $e_t^j = q_t^j$ in country j. It is important to clarify that the relationship between emission and production does not have to be necessarily linear. However, this assumption allows a simple expression for the emission dynamic to show the main insights when markets operate under imperfection. Note that some researchers have also adopted this assumption, arguing that this linearity is justified when companies do not allocate resources towards abatement [29,30]. Using this assumption and Equation (12), the dynamic model for agricultural emission is represented as:

$$e_t^i = \left(\frac{1-b_2}{b_1-b_2}\right)\left[e_0^i - e^{iN}\right]b_1^t + \left(\frac{1-b_1}{b_1-b_2}\right)\left[e^{iN} - e_0^i\right]b_2^t + e^{iN} \quad (13)$$

where $e^{iN} = \frac{\alpha-2c_i+c_j}{3}$ is the level of emission in country i in the Nash equilibrium, and e_0^i represents the initial condition of the model in terms of an initial level of emission in period $t = 0$.

Let us finish this section explaining the main features of the dynamic model, presented in Equation (13). In this expression, the term $\left(\frac{1-b_2}{b_1-b_2}\right)\left[e_0^i - e^{iN}\right]b_1^t$ shows the direct dynamic adjustment that leads to the Nash equilibrium when $e_0^i \neq e^{iN}$, and it is inferred from the fact that the coefficient b_1^t is positive. That is, any deviation from the Nash equilibrium represented by the term $\left[e_0^i - e^{iN}\right]$, which is amplified by the term $\left(\frac{1-b_2}{b_1-b_2}\right)$, will dissipate as long as $0 < b_1^t < 1$. If $b_1^t > 1$, then the model would be explosive and no convergence towards the Nash equilibrium would be verified.

On the other hand, the term $\left(\frac{1-b_1}{b_1-b_2}\right)\left[e^{iN} - e_0^i\right]b_2^t$ represents the oscillating adjustment towards the long-run Nash equilibrium when $e_0^i \neq e^{iN}$, and it is inferred from the fact that b_2^t is negative. In this case, the oscillations around the Nash equilibrium can be understood as overreactions by the producers when they have incomplete information about future prices and, therefore, about the future output produced by their competitors.

Having described the dynamic model for emissions, some relevant results regarding beneficial, sustainable policies to mitigate emissions are discussed as follows.

3. Results and Discussion

Before studying sustainable policies to address the issue of agricultural emissions, this section starts by exploring whether the dynamic model presented in Equation (13) converges to the long-run Nash equilibrium because this is vital information for the analysis on sustainable policies. This is presented in the following proposition.

Proposition 1. *Consider the dynamic model presented in Equation (13). For any shock that affects this model, it converges to the long-run Nash equilibrium.*

Proof. According to the standard solution for difference equations [31,32], Equation (13) converges to a steady state or long-run equilibrium when the parameters b_1 and b_2, in absolute value, are both smaller than 1 and larger or equal to 0. This is proved as follows.

First, it is proved that $0 \leq b_1 < 1$. Remember that $b_1 = \frac{\phi_1+\sqrt{\phi_1^2+4\phi_2}}{2}$, $\phi_1 = \frac{(1-\lambda)\gamma+(1-\gamma)\lambda}{4-(1-\lambda)(1-\gamma)}$ and $\phi_2 = \frac{\lambda\gamma}{4-(1-\lambda)(1-\gamma)}$. It is inferred from these expressions that $b_1 = 0$ when $\lambda = \gamma = 0$. That is, when producers have perfect forecast about the output that will be produced by the competitors in the next period. On the other hand, when $\lambda = \gamma = 1$, $\phi_1 = 0$ and $\phi_2 > 0$, implying that in this case $b_1 > 0$. Finally, for any $0 < \lambda, \gamma < 1, \phi_1 > 0$ and $\phi_2 > 0$, implying that in this case $b_1 > 0$. Let us now show that $b_1 < 1$. It is straightforward to show that condition $b_1 < 1$ is equivalent to $\phi_1 + \phi_2 < 1$. Replacing by the definition of these parameters and rearranging terms, it is obtained that $0 < 3$, which is always true. It must conclude, therefore, that $0 \leq b_1 < 1$.

It is proved now that $0 \leq |b_2| < 1$. First, note that $b_2 = \frac{\phi_1-\sqrt{\phi_1^2+4\phi_2}}{2} = 0$ when $\lambda = \gamma = 0$, or when $\lambda = 0$ and $\gamma \neq 0$, or when $\lambda \neq 0$ and $\gamma = 0$. On the other hand, when $\lambda = \gamma = 1$, $\phi_1 = 0$, implying that $b_2 = -\sqrt{\phi_2} < 0$. Finally, for any $0 < \lambda, \gamma < 1$, $\phi_1 > 0$ and $\phi_2 > 0$, implying that, in this case, $b_2 < 0$. From these observations, it is concluded that $0 \leq |b_2|$. The final step to prove the proposition is to show that $|b_2| < 1$. It is known from the results above that $b_1 = \frac{\phi_1+\sqrt{\phi_1^2+4\phi_2}}{2} < 1$. By transitivity, this implies that $\frac{\sqrt{\phi_1^2+4\phi_2}-\phi_1}{2} < \frac{\phi_1+\sqrt{\phi_1^2+4\phi_2}}{2} < 1$. But for definition, it is known that $|b_2| = \frac{\sqrt{\phi_1^2+4\phi_2}-\phi_1}{2}$, implying that $|b_2| < 1$ and the proof is complete. □

Proposition 1 shows the role of the learning process under imperfect competition and uncertainty. According to the results, there is always convergence towards the Nash equilibrium when two countries compete in the same market, independently of the belief of the firms respect to their competitors. Thus, any shock that impacts this economy will dissipate on time until the Nash equilibrium is reached. Nonetheless, it is important to clarify that when producers have better information to forecast the possible output the competitors will produce, the convergence towards the Nash equilibrium becomes faster. In the limit, when λ and γ are equal to zero, that is, when there is a perfect forecast, the convergence is instantaneous.

This is explained by the expectation process of farmers. That is, when they consider a fraction of the current output produced by the competitors (i.e., when λ and γ are different from zero), they make systematic price forecasting errors when the trade system is in disequilibrium. However, they adjust their predictions over time, reducing the price forecasting errors until the new equilibrium is reached. The speed of this adjustment will depend on the weight that farmers put on the current output produced by the competitors and the information they have about the future production of these competitors. To illustrate this fact, let us consider the following numerical example. Consider Equation (13) and assume $\alpha = 50$ and $c_i = c_j = 4$. Then, assume a shock consisting of an increase in the marginal cost faced by the producer in country *j* from $c_j = 4$ to $c_j = 9$. If $\lambda = \gamma = 0.8$ (i.e., when producers base their expectation mainly on the current output produced by their competitors), then the economy will converge to the long-run equilibrium in 22 periods. In contrast, if $\lambda = \gamma = 0.05$ (i.e., when producers have partial information about the future output of the competitors and put a small weight on the current production of these competitors when forming their expectations), then shock will dissipate in seven periods.

This result has an important implication for policy design. That is, environmental policies can be considered shocks that can trigger emission volatility in the short/medium run when farmers consider a fraction of the current output produced by the competitors when forming their expectations about future prices. This also implies that the beneficial effects of these policies will only be perceived in the long run when volatility dissipates in the convergence path towards the Nash equilibrium. This volatility in terms of emission fluctuations over time could be reduced by providing producers with relevant information about the competitor strategies. This would reduce emission volatility and speed up the convergence towards the steady-state equilibrium. This could be achieved by interchanging relevant economic statistics between competitor countries. For this purpose, international collaboration would be required which is one of the aims of the Climate Club. Anther strategy that may work is the adoption of market contract schemes designed to mitigate emission volatility.

Let us now consider the role of specific types of environmental policies aimed at reducing agricultural emissions. For simplicity, it is considered policies that increase production costs to reduce this emission (e.g., a tax on production or the elimination of an input subsidy). In particular, two possible policies are distinguished: a policy that is applied unilaterally by a country; and a policy that is applied by both competitor countries simultaneously. These possibilities are studied as follows.

Let us start with a policy applied unilaterally by country *j* (the same results will be obtained if the policy is applied unilaterally by country *i*). The following proposition shows that this policy creates volatility in the short/medium-run and adverse side effects on the competitor country.

Proposition 2. *A unilateral policy applied by a determined country j to reduce agricultural emissions in the same country will cause (i) emission volatility in the short/medium run in both* *competitor countries; (ii) a decrease in emissions in country j; and (iii) an increase in emissions in the competitor country i.*

Proof. To prove this proposition, consider first the emission that is consistent with long-run Nash equilibrium in countries i and j, respectively, before the policy is implemented in country j: $e^{iN} = \frac{\alpha-2c_i+c_j}{3}$; and $e^{jN} = \frac{\alpha-2c_j+c_i}{3}$. Let us take the first derivative of these expressions with respect to c_j to assess the long-run effect of the policy adopted in country j. These derivatives are $\frac{\partial e^{iN}}{\partial c_j} = \frac{1}{3} > 0$ and $\frac{\partial e^{jN}}{\partial c_j} = \frac{-2}{3} < 0$. This means that the policy causes an increase in emissions in country i and a decrease in emissions in country j in the new long-run equilibrium. On the other hand, let $e_0^i = e^{iN}$ and $e_0^j = e^{jN}$ be the emission in the original Nash equilibrium in countries i and j, respectively. Likewise, let e^{iN*} and e^{jN*} be the emission that is consistent with the new Nash equilibrium in countries i and j resulting from the unilateral policy. Using Equation (13) and these definitions, the following expressions are obtained for the dynamic emission in these countries: $e_t^i = \left(\frac{1-b_2}{b_1-b_2}\right)\left[e_0^i - e^{iN*}\right]b_1^t + \left(\frac{1-b_1}{b_1-b_2}\right)\left[e^{iN*} - e_0^i\right]b_2^t + e^{iN*}$ and $e_t^j = \left(\frac{1-b_2}{b_1-b_2}\right)\left[e_0^j - e^{jN*}\right]b_1^t + \left(\frac{1-b_1}{b_1-b_2}\right)\left[e^{jN*} - e_0^j\right]b_2^t + e^{jN*}$. Because $e^{iN*} \neq e_0^i$ and $e^{jN*} \neq e_0^j$, $\left(\frac{1-b_2}{b_1-b_2}\right)\left[e_0^i - e^{iN*}\right]b_1^t + \left(\frac{1-b_1}{b_1-b_2}\right)\left[e^{iN*} - e_0^i\right]b_2^t$ and $\left(\frac{1-b_2}{b_1-b_2}\right)\left[e_0^j - e^{jN*}\right]b_1^t + \left(\frac{1-b_1}{b_1-b_2}\right)\left[e^{jN*} - e_0^j\right]b_2^t$ are both different from zero, implying that the policy triggers emission volatility in both countries and the proof is complete. □

This result shows that a unilateral policy not only creates volatility, but also increases emission in the competitor country. That is, the country that applies the policy also exports emission to the competitor country suggesting that the emission problem has not fully been solved from this policy. This adverse effect on the competitor country will be perceived in the long run, when volatility dissipates in the adjustment process.

This result may explain part of the trends observed in the real world. As described in the literature review, current evidence has revealed that CO_2, CH_4 and N_2O emissions from energy use in agriculture (including fossil-fuel and electricity) have decreased in developed countries but has increased in developing countries [11]. This may reflect that strict environmental regulations in developed countries are exporting environmental problems to countries with less strict regulations. Our theoretical framework offers an economic mechanism to explain this evidence-based, as previously explained, on the presence of market failures in the agricultural trade system.

Considering this result, an obvious question is what type of environmental policy could be sustainable in the sense that it does not create adverse side effects on third countries. The answer is given in the following proposition.

Proposition 3. *A policy applied simultaneously by the competitor countries reduces emissions in both countries (i.e., does not create adverse side effects), although it may cause volatility in the short/medium run.*

Proof. To prove this proposition, consider the emission that is consistent with long-run Nash equilibrium in countries i and j, respectively, before the policy is implemented in country j: $e^{iN} = \frac{\alpha-2c_i+c_j}{3}$; and $e^{jN} = \frac{\alpha-2c_j+c_i}{3}$. To assess the impact of a simultaneous policy adopted by both countries, totally differentiating these expressions is needed. The results are: $de^{iN} = \frac{\partial e^{iN}}{\partial c_i}dc_i + \frac{\partial e^{iN}}{\partial c_j}dc_j = -\frac{1}{3} < 0$; and $de^{jN} = \frac{\partial e^{jN}}{\partial c_i}dc_i + \frac{\partial e^{jN}}{\partial c_j}dc_j = -\frac{1}{3} < 0$. This means that the emission that is consistent with the Nash equilibrium decreases in both countries when they adopt simultaneously the policy, implying no adverse side effects on these countries. In relation to volatility, this is inferred from the same analysis given in Proposition 2. That is, a change in the Nash equilibrium triggers the dynamic part of the dynamic equations for countries i and j. □

This significant result revealed that a sustainable environmental policy could reduce emissions without causing negative externalities when adopted simultaneously by the competitor countries. This suggests that collaboration across countries is a key aspect that should be considered when designing policies and when international markets operate under market failures. While emission volatility cannot be eliminated from this collaboration, it can be reduced by helping producers in different countries to improve their forecast of the strategies adopted by the competitor countries. However, this is not a simple task because private producer may not be willing to reveal their future output strategies. Nonetheless, implementing better market information and encouraging farmers to adopt market contract strategies may help reduce this volatility. This, in turn, would speed up the beneficial impact of the sustainable policy.

4. Conclusions

This article explores the issue of agricultural trade, agricultural emissions and environmental policy when market failures affect the international trade system of agricultural and food-processed goods. These failures correspond to producer uncertainty about the prices they will receive when selling their production and the existence of an oligopoly in international markets.

Using a dynamic theoretical framework that includes these market failures, it was found that environmental policies can be considered shocks because they cause instability and emission volatility in the short/medium run when producers do not have a perfect forecast about the output strategies of the competitors and, therefore, about the price they will obtain when selling their production. This volatility dissipates over time until a new long-run equilibrium is reached, suggesting that the effects of these policies would be perceived only in the long-run. The period in which this volatility dissipates depends on how relevant the ex ante price uncertainty for the producers is. That is, the transition to the new equilibrium will be faster when producers have more certainty about future prices.

The results also revealed that unilateral policies (defined as policies that either tax the production or eliminate existing input subsidies) adopted by one of the competitor countries cause negative externalities in third countries in terms of higher agricultural emissions. Finally, the model shows that a beneficial environmental policy would be the one that is applied simultaneously by the competitor countries.

This result has two main implications. First, a beneficial policy requires international cooperation and coordination between countries. Second, reducing emission volatility could be achieved by interchanging relevant economic statistics between competitor countries, also in a context of international cooperation. The adoption of market contract schemes designed to mitigate emission volatility is another possible feasible strategy.

This research has the following novel contributions. First, the general objective of the Climate Club is to limit emission by means of international collaboration. The proposed theoretical model contributes to this objective by providing an explicit policy formula to limit agricultural emissions that is based on international collaboration. Second, the proposed model alerts about possible unintentional negative side effects of policies that are designed to address domestic agricultural emission. (e.g., regulations developed to reduce air pollution from biomass combustion, Yu and Gu [33]). As explained above, they include increased emissions in competitor countries and increased emission volatility in the short/medium run. In this context, the model can be considered as the basis for the design of strategies that could be used to mitigate these side effects. Third, the proposed theoretical approach offers an explicit mechanism that explains the connection between agricultural trade and the environment. This contributes to this research area because the relationship between agricultural trade and the environment is still not well understood, and most of the works that consider this connection are based on empirical work [13,34]. Finally, while the model considers the impact of policies that affect the marginal cost faced by producers, it is flexible enough to explore the dynamic impact of other types of policies that have been proposed in the literature in the context of international trade in agriculture. For example, changes in consumer habits [13]. This can be achieved by adopting, for instance, differentiated goods into the analysis.

This article is finished by explaining some limitations of the research. First, the proposed dynamic model cannot be generalized to other sectors except when they also have similar market failures. Second, the model assumes that farmers have adaptive expectations about future prices. However, other approaches, such as the one referred to as rational expectations, may lead to different results in terms of emission volatility. Third, emission was assumed to be linearly related to the produced output. Considering nonlinearity in the dynamic framework may lead to multiple equilibria or nonlinear paths toward a single equilibrium. Finally, the proposed model is a simplification of reality, and the real world is much more complex. Given these limitations, the results obtained in the research have to be considered with caution. However, this model can be the basis for extensions and more complex theoretical and empirical analyses. All these limitations will be addressed as extensions for future research.

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