International aggregate agricultural supply for grain and oilseed: the effects of efficiency and technological change

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Abstract

This paper analyses the effects of the main determinants of international aggregate agricultural supply. We propose a new model which captures the farmers' expectations through the storage approach, instead of using Nerlove's basic model. As an innovation, we add the effects of efficiency and technological change directly, thus achieving a more powerful and informative estimation than with the usual dynamic model. Moreover, we consider the effect of climate and construct a sowing and harvesting calendar for each country and each crop to measure the supply more precisely. We also analyse the effects of agricultural prices and their volatility, of commercial policy and of changes in inventories on the suppliers' decisions. Finally, we examine the differences in these determinants depending on the level of development of the countries.

Keywords: Agricultural production; Efficiency and technology change; Storage model and expectations; Price elasticity; Agricultural policies.

JEL Code: Q11, Q16 and Q18.

Introduction

In the study of aggregate agricultural supply, among the most important questions, both in theoretical and in empirical work, are improvements in productivity, in efficiency and in technological change. Nevertheless, there are no studies that analyse and measure the direct effect of these factors on the international aggregate agricultural supply.

The main goal of the paper is to analyse and measure the direct effect of efficiency and technological change on the international aggregate agricultural supply. We propose a model which offers two important innovations. The first is a new interpretation of the expectations component from the so-called storage model. This allows us to avoid the autoregressive scheme typical of Nerlove's basic model (1956 and 1958). The second innovation is that it separately considers the effects of efficiency change and technological change on the aggregate agricultural supply.

It is important to insist that the inclusion of the autoregressive scheme, as in the classic Nerlove's model, produces important problems for the econometric estimations; its inclusion is just the result of an ad-hoc assumption which is inaccurate (Nerlove, 1979). Our empirical analysis confirms that the storage model approach is a good tool to measure the effect of the expectations about the formation of prices in the agricultural sector.

We have also found that the inclusion of efficiency change and technological change increases the explanatory power of the proposed model compared to the autorregresive Nerlove's model. Thus, we confirm that this autorregresive component, more than capturing the effect of expectations on prices, is absorbing the effect of the variations in the sector's productivity.

Our analysis uses a large sample of representative grains and oilseeds from many countries, which required a great effort to collect and construct. Moreover, we have constructed an international sowing and harvesting calendar by crop and country, which is an essential contribution to the measurement of the aggregate agricultural supply and substantially improves the precision of the analysis. We aim to obtain a more accurate estimate of the effects of changes in fundamental factors, such as prices, economic policy, productive efficiency and international technology change on the aggregate agricultural supply. Moreover, we study the possible different impacts in each country depending on their level of development.

We obtain that both efficiency change and technological change have an important positive effect on the aggregate agricultural supply so they should be taken into account to promote agricultural development. Regarding the effect of prices, we confirmed a low elasticity of the aggregate agricultural supply. Trade policies are effective if they use taxes over prices but they never obtain a significant effect if they use subsidies. Using a novel climate variable, we found a significant impact of adverse effects. Finally, we found that efficiency has a larger effect in highly developed countries while technological change is more important in countries with a lower development level.

The paper is organized as follows. In Section 1, we review the main literature on the subject. In Section 2, we develop the theoretical framework. In Section 3, we describe the procedures employed to construct the sample and the variables used in the analysis. The econometric models and empirical estimation are presented in Section 4. Section 5 concludes.

1. Background of the analysis of the agricultural supply

At the end of the 80s and 90s, several works analysed the agricultural supply and estimated its price elasticities. The most cited works include those by Rao (1989) and Schiff and Montenegro (1997), among others, and in general, the results obtained are heterogeneous. Onal (2012) indicates that the debate on the long-term elasticities remains open. He also suggests that the apparent low elasticity of the aggregate agricultural supply, obtained in many econometric estimations, may be caused by an omitted variables bias; the omitted variables may be the availability of infrastructures, access to credit and technology, and the institutional framework, which could have a direct effect on the transaction costs.

Kiel et al. (2000) have demonstrated that a reduction in the transaction costs has a positive effect on the agricultural supply. Therefore, they suggest that any price policy applied to the agricultural sector must be accompanied by a series of measures to reduce these costs, in other words, to improve the economic efficiency. So it can be expected that an improvement in the institutional framework which reduces the transaction costs and improves the social infrastructure will yield an increase in the price elasticity of the agricultural supply (Schiff, 1987; Schiff and Montenegro, 1997; and Onal, 2012, among others).

In the less developed countries, Bloom and Sachs (1998) indicate that the low price elasticity of the agricultural supply it might also be caused by the low fertility of the soils and by other technical and climatic factors, all of them reducing the farmers' ability to respond to changes in the prices. Moreover, it has been noted that although prices are a relevant factor, geological and technical factors are even more important (Kanwar, 2006 and FAO, 2009).

The analysis of price elasticity *versus* the elasticity of the response to the provision of public goods and other factors has been tackled by several authors. Nerlove (1979) indicated that, in order to understand the dynamics of the agricultural supply, the more general causes of the changes produced in the sector have to be considered. So it is necessary to analyse the effect of technological changes, public investment and factors that condition the economic agents' ability to respond to the market imbalances.

Binswanger et al. (1987) is one of the first contributions that considers the technological component in the agricultural supply function, although it mainly focuses on the influence of the variables related to capital stock, both physical and human, rather than on the technological component directly. Their findings recognize the importance of capital accumulation, although they also draw attention to the possible endogeneity between it and the technological component, which is caused mainly by the kind of variable used to measure the latter.

In conclusion, environmental variables, which determine the levels of economic efficiency, and the technological effect, are found to be essential factors. Delgado and Mellor (1984) and Platteau (1996) have argued that the price elasticity is lower than that of the other factors not captured by the prices, in general characterized by the institutional framework. Additionally, Schiff and Valdez (1992) have noted that the debate on the price elasticity of supply does not make sense if the general conditions of the economic environment are not observed.

More recently, Subervie (2008) relates the effect of the volatility of international prices to the local macroeconomic factors, and analyses its impact on the aggregate agricultural supply. Her study indicates that the local macroeconomic framework in which the producers operate very often conditions their ability to respond to changes in international prices. She finds a negative and significant relationship between the price volatility and the world agricultural supply. Furthermore, she finds a larger effect in those countries with a high inflation rate, those with an inappropriate development of the financial system and those lacking good infrastructures.

The phenomenon of price volatility and its effects on the agricultural supply has long been observed. Recently, the topic has received a new boost, for instance in the works of Haile et al. (2013 and 2014). These authors analyse individual crops and find certain evidence of a negative effect of price volatility on the farmers' sowing decisions. Besides this, some studies obtain that a certain degree of price volatility is common in agriculture because of the seasonal component of demand, the climatic component and the losses due to plagues and other natural disasters (FAO, 2012).

In fact, the effect of price volatility is relevant, especially when the volatility is high or when it can not be anticipated. In other words, volatility becomes a problem when there are price variations that can not be explained by changes in their fundamentals (FAO et al. 2011). The fact that farmers are used to living with a certain degree of price volatility would weaken the basis of the risk aversion assumption.

In the theoretical model we present below, we take into account two possible cases. First, if the agricultural production responds to the risk aversion assumption, the price volatility effect will be negative. On the other hand, if the volatility stimulates the speculative component, a positive effect will be expected.

2. The model

Most of the contributions to the analysis of the effects of public policies and other determinants of the agricultural supply are based on Nerlove's basic model (1956 and 1958), with the addition of other explanatory variables. Nevertheless, and despite its popularity, it is worth considering some of its limitations. The main limitation has to do with the autoregressive scheme that appears when the lagged dependent variable is included as a regressor, leading to serial correlation, multicollinearity and the endogeneity problem.

One of the first contributions to draw attention to these problems is Braulke (1982), who indicates that the differences observed in the estimations obtained in the literature are caused by the multicollinearity problem, due to the contemporaneous relationship between prices and production. LaFrance and Burt (1983) provide a solution based on a theoretical framework in which the autorregresive structure of the model disappears.

Therefore, in order to more accurately capture the effects of expectations, we propose a new approach based on the storage model instead of the autorregresive component approach in which Nerlove's model is based. In this way, the agricultural supply can be represented by the following expression:

$$Q_{jt} = F\left(A_{it-1}, W_{jt},\ TFP_{it-1}\right) \tag{1}$$

$$TFP_{jt-1} = G(\ E_{it-1}, T_{t-1}) \tag{2}$$

where $\boldsymbol{Q}$ is a measurement of the production level, $\boldsymbol{A}$ is the cultivated area, $\boldsymbol{W}$ is a measurement of the impact of the climatic conditions, which is not lagged because this variable affects the output during the production process.

$\boldsymbol{TFP}$ represents the technical and economic framework in which each farmer take his decisions. In general, TFP captures two effects, one characterized by improvements in the economic efficiency conditions and the other reflecting technological improvements that push the production frontier. So, in the TFP we can distinguish one effect that moves inside the frontier and aims to improve the productive efficiency in each economy in relation to the international frontier (E_i), and another that widens the global productive horizon in each period t because of the technological impact (T), in a similar way to the one conceptualized by Farrell (1957).

The farmer's decision about the area to be cultivated is a function of the expected prices (P_{it}^{e}) and, moreover, it is conditioned by the current trade policy applied on prices (CP_{it}):

$$A_{it} = H(P_{it}^{e}\ ,\ CP_{it},) \tag{3}$$

However, given that P_{it}^{e}can not be observed, we have to use a proxy. One of the most common comes from the pioneer work of Nerlove (1956 and 1958). This author suggested a function with weighted moving averages of the price observed in previous periods in order to proxy its value, so the model is one of adaptative expectations.

In our model, we assume that the agricultural producer continuously observes the movements of prices. Thus, an increase in the international price usually yields a decrease in the stocks of the period. This will create a scenario of "good" prices in the next period, because the consumption demand is maintained, or because of the using up of the stocks to re-establish the former levels.

The storage model is one of the best proposals to explain the movements of agricultural prices (Stigler, 2011). For this reason, we suggest an alternative way of specifying the expected price function on which the farmer bases his sowing decisions and whose calculation considers the stock levels and the current prices at sowing time.

We derive the equation that determines the expected price in the theoretical framework proposed by Pindyck (1993). The expected price function is specified as follows:

$$P_{it}^{e} = (1+\theta)P_{it} - c_{it} \quad (4)$$

where P is the price of the commodity and P^e its expected price. c is the net marginal convenience yield, that is, after discounting the operational and storage costs. Parameter θ is the risk adjusted discount rate that, as in Pindyck, we assume to be constant. Moreover, the storage model postulates an inverse relationship between the stock levels and the net marginal convenience yield; according to this, when the stock (I) increases, the net marginal convenience yield (c) decreases in the same measure, mainly because of the rise in the storage price and because the demand is an inverse function[1].

Another determinant to be considered is international price volatility (σ). Its effect on production can be observed in two ways. The first, according to Pindyck (2001), using a direct and positive relationship between c and price volatility:

$$c_{it} = U[-\gamma\Delta I_{it}, \delta\sigma_{it}] \quad (5)$$

Combining (4) and (5) we get:

$$P_{it}^{e} = (1+\theta)P_{it} + \gamma\Delta I_{it} - \delta\sigma_{it} \quad (6)$$

[1] This relationship is confirmed by Knetsch (2006) and Alquist et al. (2014).

In this case, the volatility of the international prices has a negative effect on the expected prices and produces a decrease in the future supply, confirming farmers' risk aversion. However, the opposite relationship can also be expected. If we expect an increasing trend in prices, a higher price volatility might increase speculative actions and this could lead to increase in the expected prices (Pindyck, 2004). So equation (6) would be written as follows:

$$P_{it}^{e} = (1+\theta)P_{it} + \gamma\Delta I_{it} + \delta\sigma_{it} \tag{7}$$

In consequence, from equations (1), (2), (3), (6) and (7) we can express the equation that defines the agricultural supply as follows:

$$Q_{it} = Y\big((1+\theta)P_{it-1} + \gamma\Delta I_{it-1} \pm \delta\sigma_{it-1};\ CP_{it-1};\ W_{it}; E_{it-1};\ T_{t-1}\big) \tag{8}$$

In other words, the agricultural supply is a function of the international prices in the previous period, the stock levels, the international prices volatility in the same period, the trade policy, the climatic effect, efficiency and the technological impact.

3. Data and variables

The information available for the calculation of the PTF and the scarce information for the economies of the former Soviet Union limit our analysis to the period comprised between 1993 and 2008.

The crops considered are grain and oilseed. More specifically, barley, corn, millet, oats, rape, rice, rye, sorghum, soybean, sunflower and wheat. In each economy, we have included only the crops that make up at least 1% of the local production.[2]

[2] Because of the lack of statistics on prices, we had to eliminate barley in the case of Argentina, sorghum in Brazil and soybean in India from the analysis.

Restrictions in the information available, especially that related to the sowing calendar, only allow us to consider 26 economies, but they constitute about 83% of the world production of grain and oilseeds and our sample forms a balanced panel with 390 observations. The list of countries as well as the crops they produce are presented in Annex 1, Table A1.

3.1. The agricultural supply

One of the most frequently used variables of supply is that which measures the area of cultivated land, because it best captures how the farmer makes his sowing decisions (Rao, 1989). Nevertheless, it is not a good variable to capture the effect of the changes in the general conditions of the institutional and macroeconomic framework or the effect of technological change. Moreover, there is not enough information on a global scale, so it is usual to employ an output variable such as the harvested area.

Although there is enough information about the harvested area, we do not think this is a good measurement of the aggregate supply behaviour, because it does not capture the effect of technological change, as a displacement of the agricultural frontier. This is mainly because the land endowments are relatively rigid, especially in the high income countries, so we do not expect this variable to be a good measure of the change in the aggregate supply. For this reason, we propose to measure the agricultural supply with the production volume in metric tonnes. This variable is capturing the effect of climate, prices and, above all, improvements in productivity. In this way, the agricultural supply variable suggested, Q, will be measured as the production in tonnes of the n crops used in the analysis [3]

The information source is FAO, which publishes the production data by natural year. Because the production dynamics of each crop responds to specific features which have to be included in

[3] It is important to note that even this measure present some problems because of possible changes in the crops basket. However, we expect they will have a minimum impact.

the analysis, we have built a sowing and harvesting calendar for each crop and for each country of the sample. These calendars are shown in Annex 1, Table A1.

In this way, the agricultural supply variable, Q_{it}, is the annual production in tonnes, in which Q_{it-1}^{A} are the crops sown and harvested in the same natural year, including crops with two harvests per year. Moreover, Q_{it}^{I} is the annual production tonnes of crops that are sown in one year and harvested during the year after, that is, in an inter-annual process. So the aggregate supply is Q_{it}, where $Q_{it} = Q_{it-1}^{A} + Q_{it}^{I}$.

3.2. Price measurement

The price index *P* must be an aggregate index. The most precise measurement (Dehn, 2000) is a weighted average for each country that takes into account the amount and the products obtained in each crop. In this way, the aggregate real price for each country i in each year t, P_{it}, is the aggregation of prices weighted by the production level, expressed as follows:

$$P_{it} = def_{it} \,.\, \textstyle\sum_{j=1}^{n} P_{jit} \,.\, w_{jit} \tag{9}$$

where P_{jit} is the nominal price paid to the producer for each agricultural commodity j, and *w* is the share of product *j* in the total production of the *n* products included in the analysis, with $\sum_{j=1}^{n} w_{jit} = 1$.

The nominal prices in Standard Local Currency and the shares of each product are from FAO. The deflator *def* is the consumer price index (CPI) in each economy with the base year 2010=100 and is obtained from the World Bank.[4]

[4] All FAO data are obtained from http://faostat.fao.org/site/291/default.aspx. In the particular case of Pakistan, the price data of rice for the years 2003 to 2007 have been completed using the annual average of the variable "INTERNATIONAL PRICES, Pakistan, Rice (25% broken), Export, (USD/tonne)", provided by http://www.fao.org/giews/pricetool/.

3.3. Variations in stock levels and price volatility

We use the variation in grain and oilseeds stocks as a proxy for the variation in stocks, ΔI, published by FAOSTAT and measured in tonnes. To measure the price volatility, we follow Subervie (2008), and use the typical deviation with respect to his trend, expressed as a variation rate. Nevertheless, we also think it is convenient to consider the differential impact of the price movements on each economy depending on the participation of each crop. For instance, a country producing mainly grain is more influenced by the price volatility of grain than that of oilseeds, and *viceversa.* So, we measure the price volatility σ with the following expression:

$$\sigma_{it} = \sqrt{\frac{1}{12}\sum_{k=0}^{12}\left(\frac{P^*_{it-k}-\hat{P}^*_{it-k}}{\hat{P}^*_{it-k}}\right)^2} \quad (10)$$

$$P^*_{it} = a + bP^*_{it-1} + ct + \mu_t \qquad \text{and} \qquad \hat{P}^*_{it} = \hat{a} + \hat{b}\hat{P}^*_{it-1} + \hat{c}t.$$

where σ is the volatility of the international prices for each country *i*. P^*_{it} is the weighted sum of the price indexes for grain and oilseeds and their oils. The World Bank offers monthly data in its Commodity Price Data (The Pink Sheet), and the calculation of P^*_{it} can be expressed as follows:

$$P^*_{it} = \left(IPG_t * wg_{it} + IPO_t * wo_{it}\right) \quad (11)$$

where *IPG* is the international prices index for grain, *IPO* is the international prices index for oilseeds and their oils, and *wg* and *wo* are the annual share of the harvested areas of grain and oilseeds, respectively, in the total production of both crops in each country. So, every year $wg + wo = 1$.[5] Moreover, we consider 12 months for the calculations, the first six months corresponding to the previous year and the last six months to the first six months in year t. In this

[5] In the case of Ethiopia, we have assigned the values of Ethiopia RDP for the year 1992. In the case of Czech Republic and Slovakia we have assigned, for the same year, the participation coefficient of 1993.

way, we obtain a measure of the international price volatility observed by the farmer at sowing time.

3.4. Trade policy

To consider the trade policy and its effect on the agricultural sector of each economy, we use the *nominal rate of assistance (NRA)*, computed by Anderson and Valenzuela (2008) and updated by Anderson and Nelgen (2013).[6] The NRA measures the relative difference between the price in US$ for each product *j* received by the farmer, the domestic price *(DP)*, and the so-called border price *(FP)* which the farmer could receive if there do not exist distortions. So the NRA for each product and country in year t is: $NRA_{jit}=(DP_{jit}/FP_{jit})-1$.[7]

Accordingly, if the frontier price is higher than the price received by the producer there will be a tax policy and the NRA will be negative. But if the domestic price is higher than the frontier price, the NRA will be capturing a subsidy policy, and the index will be positive.

Given that an index built in this way is capturing two opposite effects from the economic policy, and that it is interesting to analyse them separately, we divide the indexes into two parts. The first, CP^{Sub} takes only the positive NRA values, indicating a subsidy, and gives a zero value to the rest of the observations. The second, CP^{Tax} , only takes the negative values of NRA and gives zero values to the rest of the observations, thus measuring a tax effect.

3.5. The effect of climate

In order to measure the climatic impact, W_{it}, we propose the use of the *Agricultural Stress Index* (ASI), a new index based on the contributions of Rojas et al. (2011) and provided by the *Global Information and Early Warning System* of FAO (FAO-GIEWS).

[6] Onal (2012) also uses the NRA as a measure of the trade policy effect. His findings for Africa, in general, are statistically non significant.

[7] In order to measure the NRA, we use an aggregate measure, defined by these authors as "nra_tott".

The ASI, in annual data, represents the percentage of arable land within an administrative area, a country in our case, which has been affected by drought during the agricultural season. For this reason, it is a measurement that captures unfavourable climatic conditions, so we expect to obtain a negative impact on production.

The drought effect is recognized as one of the most important effects of the weather on agricultural production (Toulmin, 1986). The ASI index is internationally comparable and it is now being considered for use in crop insurance, given its importance to predict the weather effects on production, as is demonstrated in Rojas and Ahmed (2016) and Van Hoolst et al. (2016). Although the importance of the weather is recognized, there is hardly any research that takes into account the impact of the weather on crop production at the international scale. Magrini et al. (2016) use the same index to measure the impact of weather on agricultural commodities prices. For this reason, it is a novel contribution to consider this new index to analyse the impact of climate on agricultural supply at the international level.

3.6. The measurement of TFP, efficiency and technological change

Finally, in order to measure the TFP, we use the *Data Envelopment Analysis* (DEA), in particular the advances presented in O'Donnell (2008, 2010, 2011 and 2012a). We have considered the output approach and used the program DPIN 3.0, as it is explained in O'Donnell (2011).

In the TFP estimations, we have assumed variable scale returns and we have allowed technological reversion over time. As the output variable, we have used the agricultural constant net production index (2004-2006 base year) in thousands of international dollars (1000 I$). We use four inputs: *Labour*, or total economically active population in agriculture; *Arable Land*, in thousands of hectares; *Capital Stock*, as the stock of gross capital in dollars at 2005 constant prices; and *Fertilizers*, measured by the total metric tons of nitrogen, phosphate and potash consumption. *Capital Stock* includes only the items "Land Development" and "Machinery and Equipment", because they are the ones with a more direct link to the crops analysed

All these data, except fertilizer consumption, are from FAOSTAT. Data on fertilizer consumption are from the *International Fertilizer Industry Association* (IFA) and from Fuglie (2012).

To decompose the TFP into technological change and efficiency, we use the Färe-Primont Index (FPI) proposed by O'Donnell (2012b). The FPI can be decomposed into two components: one is the technological change (TC) component which measures a shift of the production frontier during a period. Its calculation results from the identification of the economic unit that shows the maximum level of TFP for a given period. The second is the efficiency change (EC) component which measures a movement of the economic unit towards (or away from) the production frontier. It means an improvement (or worsening) in the efficient use of the production factors.

In O'Donnell (2008, 2010 and 2011), the reader can find full details about this technique and, in Le Clech and Fillat-Castejón (2016), the authors apply these advances to the agricultural sector and explain the advantages of the FPI index.

A summary table of the TFP estimations is shown in Annex 2.

4 Econometric models and estimation of aggregate supply

The model to be estimated and which comprises all the determinants considered in the theoretical model expressed in equation (8) can be represented as follows:

$$lnQ_{it} = \alpha_0 + \beta_1 lnP_{it-1} + \beta_2 \Delta I_{it-1} \pm \beta_3 ln\sigma_{it-1} + \beta_4\, CP_{it-1}^{Sub} + \beta_5 CP_{it-1}^{Tax} + \beta_6 lnW_{it} + \beta_7 lnE_{it-1} + \beta_8 lnT_{t-1} + \epsilon_{it} \quad (12)$$

where lnQ_{it} is the aggregate agricultural supply, lnP_{it-1} is the price variable, ΔI_{it-1} and σ_{it-1} are the variables variations in stock levels and price volatility, respectively. The climatic variable is W_{it} , and lnE_{it-1} and lnT_{t-1} are the measurements of economic efficiency and international technological change. *ln* indicates that the variable is measured in logarithms, so the coefficients are elasticities, and Δ indicates an operator in first differences. Finally, the error term can be represented as $\epsilon_{it} = \alpha_i + \mu_{it}$. It contains two components, one capturing the individual effects of each cross-section unit (α_i), and other totally random (μ_{it}), which captures the phenomena not explained by the model and that vary by country and year. In our estimations, the fixed effects model is the most accurate given the particularities of our sample.

We also test the effect of the inclusion of the lagged dependent variable in the regressors, in order to analyse the dynamic effect in equation (8), as an extended Nerlove's model. We evaluate two alternatives: one includes the variables of efficiency and technological change, and the other does not, expressed in equations (13) and (14), respectively:

$$lnQ_{it} = \alpha_0 + +\rho lnQ_{it-1} + \beta_1 lnP_{it-1} + \beta_2 \Delta I_{it-1} \pm \beta_3 ln\sigma_{it-1} + \beta_4\, CP^{Sub}_{it-1} + \beta_5 CP^{Tax}_{it-1} + \beta_6 lnW_{it} + \beta_7 lnE_{it-1} + \beta_8 lnT_{t-1} + \epsilon_{it} \qquad (13)$$

$$lnQ_{it} = \alpha_0 + \rho lnQ_{it-1} + \beta_1 lnP_{it-1} + \beta_2 \Delta I_{it-1} \pm \beta_3 ln\sigma_{it-1} + \beta_4\, CP^{Sub}_{it-1} + \beta_5 CP^{Tax}_{it-1} + \beta_6 lnW_{it} + \epsilon_{it} \qquad (14)$$

As can be seen in Table 1, the OLS estimation of equation (12) indicates heteroscedasticity and cross sectional dependence (CSD) problems. Following De Hoyos and Sarafidis (2006), in order to avoid these problems we can use the instrumental variables technique, Two Stage Least Square (TSLS). This proposal is especially important to estimate equations (13) and (14) because there is a problem of endogeneity when the lagged dependent variable is introduced.[8]

[8] It is important to note that we have considered the Generalized Method of Moments (GMM) technique. However, we have observed that the results obtained are very sensitive to small variations in the specification. These results

The instrumental variables technique yields consistent but not necessarily efficient estimates of the parameters. One alternative to solve the problem of losing efficiency, calculating standard errors which are consistent with CSD, is the proposal of Driscoll and Kraay (1998) (DK). Moreover, the standard errors suggested by DK are efficient not only in the presence of CSD but also in the presence of heteroscedasticity (Hoechle, 2007). In general, the OLS-DK estimations yield consistent and efficient results when the CSD is caused by common factors in the sample countries and these factors are not correlated with the regressors. [9]

Finally, there are two interesting alternatives. One is Park's Feasible Generalized Least Squares (FGLS), and the other is the Panel Corrected Standard Errors technique (PCSE). Beck and Katz (1995) have demonstrated that the PCSE technique is very robust in terms of the efficiency obtained in the standard errors. However, Reed and Ye (2011) indicate that the features of the sample have to be taken into account. In this way, when the cross-section dimension is larger than the time dimension, the PCSE technique yields better results than the FGLS. But, when the time dimension is, at least, 1.5 times larger than the cross-section dimension, the FGLS technique obtains better results than the PCSE.

Table 1 shows the results of the different estimation alternatives. For the TSLS technique we use three variables as instruments. The World Gross Domestic Product (WGDP) and the Gross Domestic Product (GDP) of each economy, both in constant values of 2010 and taken from the USDA Macroeconomic International Data. We also use the climatic variable. In equations (13) and (14) the assumed endogenous variable is the lagged dependent variable. However, in equation (12) the assumed endogenous variables are efficiency and technological change. In all cases, Jansen's overidentification test is performed. In equation (12) we also carry out the

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are in line with those in Roodman (2009), who attracted attention to these particularities indicating the high probability of "false positives" when the GMM is used.

[9] In our case, it is possible to expect that the CSD responds to common factors, such as the global demand behaviour. However, it is more difficult to assume that these factors are not correlated with the regressors, so we have to be cautious in the interpretation of the results.

Davidson and MacKinnon's (1993) exogeneity test, confirming the exogeneity of efficiency and technological change.[10]

The results obtained for the TSLS estimations confirm one of the hypotheses of the paper: the dynamic component in Nerlove's basic model is capturing the effect that corresponds to the determinants of the productivity change, instead of the expectations component. This can be observed in the TSLS estimations of equations (13) and (14). In the first, the lagged variable is not significant and the sign is the opposite to that expected. In equation (14) the results are in line with Nerlove's model, with a short-run elasticity of 0.149 and a long-run elasticity of 0.560. However, the explanatory power of the model falls sharply, with an R^2 of 0.142, compared to an R^2 of 0.519 in the estimation corresponding to equation (12). The model including efficiency and technological change components, in equation (12), offers a better fit in the estimations and richer information than that of the lagged dependent variable (equation 14).

Given the features of the sample and following the suggestions of Reed and Ye (2011), the results of the estimation with PCSE are the most robust. We can note that the parameters estimated with PCSE yield a result very similar to the ones estimated with MCO-DK. The price elasticity of supply reaches a value around 0.10 and 0.15, similar to the results obtained by other authors, such as Roberts and Schlenker (2013), who find values varying between 0.08 and 0.13.

This low price elasticity of supply, together with the frequent non significance of the trade policy of subsidies, suggest the existence of very little room for economic policies that aim to affect prices in order to promote agriculture. With respect to tax policies, in the estimations of equation (12) we find a negative coefficient and, in general, not significant. It is convenient to remember that this variable measures the difference between the price received by the farmers and the one they could get in a market without interventions. So an estimated coefficient of about -0.3

[10] The null hypothesis Ho is that $\ln E_i$ and $\ln T$ are exogenous. We obtain a statistic of 0.802 with a p-value=0.4494.

indicates that, for each percentage point of increase in the gap between the market prices and the ones received by the producers, the agricultural supply falls by 0.3%.

The variable of variation in stock levels (ΔI) shows a positive and significant coefficient, as was expected. According to Brennan (1958), it is possible that an increase in the stock volumes yields a reduction of the *net marginal convenience yield*, pushing up the expected prices. This positive relationship between the variations in stock levels and production, implies the existence of a negative relationship between the former and the net marginal convenience yield, confirming this relationship in the international agricultural market.

The volatility of international prices has no significant effect, with the exception of the FGLS estimation, where it has a positive effect with a significance lower than 10%.[11]

In all the estimations, the efficiency variable (E_i) and the technological change (T) have an important positive and highly significant effect. For this reason, a clearly useful economic policy to promote the development of the agricultural sector is one focused on stimulating technical change and efficiency improvement in this sector.

5 Differences depending on the level of development

The literature shows disparities in the behaviour of the agricultural supply when the countries have different levels of development. In order to analyse this matter, we divide the sample, following the classification of the World Bank, into high income countries (HI) and non-high income countries (NHI). This division generates two subsamples with 9 High Income (HI) countries (Australia, Canada, France, Germany, Italy, Japan, Spain, UK and USA) and 17 Non-High income (NHI) countries (Argentina, Bangladesh, Brazil, China, Egypt, Hungary, India, Indonesia, Mexico, Nigeria, Philippines, Poland, Romania, Russia, South Africa, Thailand and

[11] We have tested other measurements of volatility, such as the standard deviation and the measurement suggested in Onal (2012, p.10), obtaining no significant effects in any case.

Turkey). We use the same period of study, so we get two balanced panels with 135 and 255 observations.[12]

The OLS estimation with fixed effects reveals that the heteroscedasticity and the CSD problems remain. For this reason, the most accurate techniques are the OLS with DK standard errors, the FGLS and the PSCE[13]. Table 2 shows all these results. The tests of the individual hypotheses yield results that are sensitive to the techniques used. However, following the recommendations of Reed and Ye (2011), the FGLS technique is the most adequate for HI and the PSCE technique for NHI.

The first striking result is that the price elasticity for HI and NHI is quite similar. Besides, it is important to note that both cases have very small price elasticities, in line with previous literature.

The variations of stock levels are positive and significant in both subsamples. In an indirect way, this finding again confirms the existence of a negative relationship between the variations in stock levels and the *net marginal convenience yield.* This relationship is slightly stronger in the less developed economies, which could be explained by different endowments of transport and storage infrastructures and a poorer development of the financial system. These differences imply that the increase in the demand for stocks have a greater impact on the operational costs in the less developed economies, reducing the marginal convenience yield more sharply.

When we analyse the effect of the variations in the international prices as a measurement of the international volatility of the reference prices, we can confirm that it is hardly significant. However, it is positive in all cases and, as for the total sample, in the FGLS estimation, the effect is positive and significant.

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[12] We base this division in the sample on the historical World Bank classification and, except Hungary, there were no changes in the classification for all countries throughout the period under analysis. Hungary was classified as a HI country only for the year 2007. For that reason, we have maintained it as NHI country.

[13] The TSLS technique is not considered because we did not observe endogeneity problems or serial correlation in the estimations of equation (12), so the other techniques are preferable.

Although these results are different from those obtained by Subervie (2008), we agree with the author that the response of the aggregate agricultural supply to the effect of price volatility is not the same in all countries. We also concur that the sign of this relationship depends strongly on the macroeconomic environment in each economy and, particularly, on the development of the financial system and the available infrastructure. For instance, in all estimations, the parameter obtained is much larger for the HI economies.

The effect of the subsidies policies is positive for HI countries, but only significant in the FGLS estimations at 10% level. In the NHI economies, the effect is negative although the results are only significant in the FLGS estimations.

The value of the tax policy variable for HI countries is always zero, so we do not report any result for this case. The effect of the tax policy for NHI countries is negative with values of around -0,225 to -0,299, double or triple the impact of the subsidies policies.

The climatic impact variable always yields a negative effect and, in general, significant. Finally, both efficiency and technological change effects are positive and highly significant. Without doubt, they are two essential variables to explain the behaviour of the agricultural supply. We note that the effect of the efficiency variable is quite similar in both groups of countries, although it is slightly larger in HI. On the contrary, technological change has a much larger effect in NHI, which might be explained by the effect of technological spillovers. In other words, the effect produced by the displacement of the technological frontier is larger for NHI countries because the technological leap for these economies is usually larger. In this sense, we might be capturing some evidence of the reduction of the technological gap between developed and less developed economies. This is a fast technological convergence in the agricultural sector, as it is warned by Marin and Miltra (2001).

6 Conclusions

To analyse the effect of the main determinants of the agricultural supply, we presented a theoretical model with two innovations. The first allows a re-interpretation of the expectations component from the so called storage model approach, in which the expectations effects are transmitted to expected prices through the impact of the variations in the stock levels on the *net marginal convenience yield.* In this way, the model captures the expectations effect and, moreover, avoids the autorregresive process of Nerlove's basic model.

The second innovation is relevant empirically because it introduces the change in TFP in the sector directly. More specifically, we examined the individual effect of two of its fundamental components: improvements in the economic efficiency and technological change.

The empirical analysis allows us to confirm that an increase in the stock levels has a positive and significant impact on the expected price. This indicates that the storage model approach is a good tool to measure the effect of the expectations on the formation of expected prices in the agricultural sector. Moreover, it is interesting to note that the effect of the variations in the stock levels is larger for NHI economies. This can be explained, essentially, by different endowments of storage and logistic infrastructures, by a different development of the financial systems which support them and, above all, by the different risk premiums of each economy. Furthermore, we could not confirm the existence of any effect of international price volatility on the farmers' expectations. Even more, the evidence found rejects the assumption of risk aversion, at least in the case of HI countries.

The empirical analysis of the impact of climate is a novelty. This measures the adverse effects of climate and always has a negative effect and this result maintains for both HI and NHI countries. Regarding the effect of prices, we confirmed a low elasticity of the aggregate agricultural supply, in general with a value lower than 0.1. We have also verified that the price elasticities of supply for HI and NHI are quite similar.

Another novelty in this paper is that we measured the effect of the trade policy, dividing it between subsidies and tax policies. In this way, we verified that the tax trade policy always presents a negative impact for the NHI countries. We have also found that, for the total sample, a subsidy policy never obtains significant results. Although these findings are important, more work in this line would be necessary.

The inclusion of economic efficiency and technological change increases the explanatory power of the proposed model. Moreover, we confirmed that the autorregresive component of Nerlove's model is not significant. Thus, this autorregresive component, more than capturing the effect of expectations on prices, is absorbing the effect of the variations in the sector's productivity.

Finally, an interesting finding is that the effect of the efficiency variable seems to be similar in both groups of countries, although slightly larger in the HI countries. However, technological change has a much larger effect in the NHI economies. This might be explained by a technological spillover effect which is responding to a process of the narrowing of the technological gap in the international agricultural sector. This fact highlights the relevance of designing openness policies that foster the absorption of new technologies.

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Table 1. Estimation of the aggregate agricultural supply (lnQ_t).

Variables	OLS- FE* (eq.12)	TSLS ** (eq.12)	TSLS ** (eq.13)	TSLS** (eq.14)	OLS-DK (eq.12)	FGLS (eq.12)	PCSE (eq.12)
lnQ_{t-1}	---	---	-0.218 (0.420)	0.734 (0.000)	---	---	---
lnP_{t-1}	0.104 (0.005)	0.123 (0.000)	0.124 (0.000)	0.149 (0.000)	0.104 (0.010)	0.117 (0.000)	0.108 (0.001)
ΔI	2.66^{-9} (0.001)	3.17^{-9} (0.000)	2.37^{-9} (0.000)	4.41^{-9} (0.001)	2.66^{-9} (0.000)	2.84^{-9} (0.010)	2.69^{-9} (0.000)
$ln\sigma_{t-1}$	0.017 (0.431)	0.207 (0.403)	0.015 (0.581)	0.044 (0.216)	0.017 (0.335)	0.027 (0.085)	0.019 (0.293)
CP^{Sub}_{t-1}	0.006 (0.915)	0.064 (0.203)	0.063 (0.200)	-0.007 (0.898)	0.006 (0.824)	0.019 (0.355)	0.008 (0.880)
CP^{Tax}_{t-1}	-0.344 (0.208)	-0.343 (0.059)	-0.381 (0.084)	-0.048 (0.807)	-0.344 (0.038)	-0.152 (0.151)	-0.284 (0.061)
lnW	-0.004 (0.222)	-0.006 (0.014)	-0.005 (0.045)	-0.006 (0.070)	-0.004 (0.012)	-0.004 (0.000)	-0.005 (0.033)
lnE_{t-1}	0.766 (0.000)	0.499 (0.006)	0.841 (0.000)	---	0.766 (0.000)	0.761 (0.000)	0.714 (0.000)
lnT_{t-1}	1.009 (0.000)	0.814 (0.000)	1.091 (0.000)	---	1.009 (0.000)	1.024 (0.000)	1.011 (0.000)
R^2	0.547	0.519	0.480	0.142	0.547	---	0.993

All estimations include transversal fixed effects. In brackets p-values.

*OLS-FE: Random effects: Hausman test, $\chi2$ = 32.42 (0.000). No serial correlation: Wooldridge (2002) test, F = 0.206 (0.654). Homoscedasticity: Wald modified test, $\chi2$ = 1414.50 (0.000), and Wiggins & Poi (2001) test, LR = 546.77 (0.000). Cross sectional dependence: Pesaran (2004) test, Stats = 3.676 (0.000); Frees (1995) test, Stats = 1.363 (0.000).

**TSLS: standard errors robust to heteroskedasticity. Additional instruments: $lnWGDP_t$, $lnGDP_{it}$, $lnGDP_{it-1}$, lnW_{it-1} y ΔlnW_{it-1}. Hansen test overidentifying restrictions: Eq. (12) $J(\chi^2)$ = 0.444 p-value = 0.9310; Eq. (13) $J(\chi^2)$ = 1.397 p-value = (0.845); Eq. (14) $J(\chi^2)$ = 5.977 p-value = (0.200).

Table 2. Estimation of the aggregate agricultural supply (lnQ_t) for High Income (HI) and Non-High Income (NHI) countries. MCO-DK, FGLS and PCSE with fixed effects.

Variables	*OLS-DK*		*FGLS*		*PCSE*	
	HI	*NHI*	*HI**	*NHI**	*HI**	*NHI**
lnP_{t-1}	0.091 (0.210)	0.094 (0.015)	0.098 (0.000)	0.092 (0.000)	0.088 (0.169)	0.092 (0.012)
ΔStock	2.03^{-9} (0.007)	2.74^{-9} (0.000)	1.89^{-9} (0.000)	2.68^{-9} (0.000)	2.02^{-9} (0.000)	2.68^{-9} (0.000)
$ln\sigma_{t-1}$	0.020 (0.575)	0.008 (0.650)	0.012 (0.489)	0.009 (0.048)	0.020 (0.661)	0.013 (0.568)
CP^{Sub}_{t-1}	0.028 (0.580)	-0.100 (0.060)	0.083 (0.084)	-0.113 (0.000)	0.022 (0.816)	-0.089 (0.315)
CP^{Tax}_{t-1}	--- ---	-0.299 (0.074)	--- ---	-0.255 (0.000)	--- ---	-0.225 (0.139)
lnW	-0.006 (0.051)	-0.004 (0.087)	-0.004 (0.003)	-0.004 (0.000)	-0.006 (0.131)	-0.005 (0.062)
lnE_{t-1}	0.953 (0.000)	0.619 (0.000)	0.932 (0.000)	0.623 (0.000)	0.954 (0.000)	0.517 (0.000)
lnT_{t-1}	0.940 (0.000)	1.111 (0.000)	0.880 (0.000)	1.091 (0.000)	0.925 (0.000)	1.116 (0.000)
R^2	0.5500	0.5887	---	---	0.9916	0.9941

In brackets p-value. ∗ Standard error normalized to the degrees of freedom.

Table 2. Estimation of the aggregate agricultural supply (lnQ_t) for High Income (HI) and Non-High Income (NHI) countries. MCO-DK, FGLS and PCSE with fixed effects.

Variables	***OLS-DK***		***FGLS***		***PCSE***	
	HI	***NHI***	***HI****	***NHI****	***HI****	***NHI****
lnP_{t-1}	0.091 (0.210)	0.094 (0.015)	0.098 (0.000)	0.092 (0.000)	0.088 (0.169)	0.092 (0.012)
ΔStock	2.03^{-9} (0.007)	2.74^{-9} (0.000)	1.89^{-9} (0.000)	2.68^{-9} (0.000)	2.02^{-9} (0.000)	2.68^{-9} (0.000)
$ln\sigma_{t-1}$	0.020 (0.575)	0.008 (0.650)	0.012 (0.489)	0.009 (0.048)	0.020 (0.661)	0.013 (0.568)
CP^{Sub}_{t-1}	0.028 (0.580)	-0.100 (0.060)	0.083 (0.084)	-0.113 (0.000)	0.022 (0.816)	-0.089 (0.315)
CP^{Tax}_{t-1}	--- ---	-0.299 (0.074)	--- ---	-0.255 (0.000)	--- ---	-0.225 (0.139)
lnW	-0.006 (0.051)	-0.004 (0.087)	-0.004 (0.003)	-0.004 (0.000)	-0.006 (0.131)	-0.005 (0.062)
lnE_{t-1}	0.953 (0.000)	0.619 (0.000)	0.932 (0.000)	0.623 (0.000)	0.954 (0.000)	0.517 (0.000)
lnT_{t-1}	0.940 (0.000)	1.111 (0.000)	0.880 (0.000)	1.091 (0.000)	0.925 (0.000)	1.116 (0.000)
R^2	0.5500	0.5887	---	---	0.9916	0.9941

In brackets p-value. ∗ Standard error normalized to the degrees of freedom.

Annex 1. Crops calendar.

This calendar is built from four different information sources. We have started with the information kindly provided by William Sacks, whose work is published in Sacks et al (2010). This information was verified and completed with the information provided by FAO, through the tool *Cropcalendar*, and the information from the Agricultural Market Information System (AMIS). We also used the information from USDA (1992).

Table A1. Crops calendar.

Country	*Barley*	*Corn*	*Millet*	*Oats*	*Rape*	*Rice*	*Rye*	*Sorghum*	*Soybean*	*Sunflower*	*Wheat*
Argentina	-	I	-	-	-	I	-	I	I	I	A
Australia	A	I	-	A	A	I	-	I	-	-	A
Bangladesh	-	-	-	-	-	Ax2	-	-	-	-	I
Brazil	-	A	-	-	-	Ax2	-	-	I	-	A
Canada	A	A	-	A (2)	A	-	-	-	A	-	Ax2
China	-	A	-	-	I	A	-	-	A	-	Ax2
Egypt	-	A	-	-	-	A	-	A	-	-	I
France	I	A	-	-	I	-	-	-	-	A	I
Germany	Ax2	A	-	A (1)	I	-	I	-	-	-	I
Hungary	Ax2 (4)	A	-	A (1)	I (1)	-	-	-	-	A	I
India	-	A	A	-	I	A	-	A	-	-	I
Indonesia	-	A	-	-	-	Ax2	-	-	Ax2	-	-
Italy	A	A	-	A (3)	-	A	-	-	A	A	I
Japan	I (5)	-	-	-	-	A	-	-	A	-	I
Mexico	A (6)	Ax2	-	-	-	A	-	A	-	-	I
Nigeria	-	I	A	-	-	A	-	A	A	-	-
Philippines	-	Ax2	-	-	-	Ax2	-	-	-	-	-
Poland	Ax2 (4)	A	-	A	I	-	I	-	-	-	I
Romania	Ax2 (7)	A	-	A (3)	-	-	-	-	-	Ax2 (7)	I
Russia	I	A	-	A	-	-	I	-	-	A	Ax2
South Africa	A	I	-	-	-	-	-	A	I	I	A
Spain	I	A	-	A (3)	-	A	-	-	-	A	I
Thailand	-	A	-	-	-	A	-	-	A	-	-
Turkey	I	A	-	-	-	A	-	-	-	A	Ax2
U.S	Ax2	A	-	-	-	A	-	A	A	-	Ax2
United Kingdom	Ax2	-	-	A (1)	I	-	-	-	-	-	I

A= Annual sowing and harvest. Ax2 = Summer and winter crops; it is treated in the same way as A. I = Sowing and harvest inter-annual. For some countries and crops there are no data. These were completed by similarities in weather and geographical conditions of the other countries: (1) Poland (2) Alaska (USA), (3) South Ukraine (4) Germany (5) South Korea (6) California (USA), (7) Italy.

Annex 2. Measurement of TFP.

Table A2. TFP Growth by country. Mean and Standard Deviation (1993-2007).

Country	Mean	Standard Deviation	Country	Mean	Standard Deviation
Argentina	0.0318	0.0611	Japan	0.0019	0.0425
Australia	0.0283	0.2279	Mexico	0.0238	0.0327
Bangladesh	0.0312	0.0571	Nigeria	0.0200	0.0366
Brazil	0.0181	0.0371	Philippines	0.0174	0.0353
Canada	0.0161	0.1043	Poland	-0.0148	0.1269
China	0.0281	0.0221	Romania	-0.0031	0.1929
Egypt	0.0300	0.0347	Russian Fed.	0.0254	0.1230
France	0.0081	0.0791	South Africa	0.0201	0.1164
Germany	0.0235	0.0955	Spain	0.0253	0.1388
Hungary	0.0133	0.1932	Thailand	0.0335	0.0449
India	0.0157	0.0552	Turkey	0.0109	0.0583
Indonesia	0.0179	0.0413	United Kingdom	-0.0016	0.0608
Italy	0.0038	0.0680	USA	0.0309	0.0983