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EXTRACTING THE KYOTO RENTS: NITROGEN EFFICIENT GMO RICE IN CHINA

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Abstract.

This paper investigates the market potential for a new technology such as a genetically modified crop, which produces both a private and a public good. A theoretical framework is developed, based on vertically differentiated products and heterogeneous producer returns. Our setting corresponds to a system composed of a biotech firm, individual farm, consumer and the government. We claim that coordination among every single stage of the system is needed in order for the adoption process to be successful and beneficial to all those involved. Our results indicate that the market adaption of a genetically modified product depends on the magnitude effect of the new technology on the incremental savings and costs as well as consumers' aversion and the carbon emission market price. In particular we consider the carbon emissions market as an important instrument associated with the reduction of the two negative parameters of production costs and consumers aversion..

Keywords: GMO, China, GHG, Public Good

JEL codes: O34, Q17, Q56

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1. Introduction

The introduction and adoption of new technologies as a response to an increasing world population has been an important feature of agriculture throughout the last decades. Genetically modified (GM) products aim to combine higher yields, improved food and feed quality with environmentally friendly agronomic practices (Phipps and Beever, 2000). However, there are many controversial issues associated with the introduction of GM products. The introduction of the first generation GM products was mainly concentrated at the producers' side via input traits such as disease or pest resistance. While the farmers' adoption of the GM products has been fairly substantial (James, 2012), there are still some fears from the consumers' side (Giannakas and Yiannaka, 2008; Kalaitzandonakes and Magnier, 2004; Hajderllari and Karantininis, 2013). Consumer opposition to first generation GM products has received considerable attention in the literature and policy-making circles and this opposition has been identified as a key determinant of both the economic effects of first generation GM products and the labeling regime of biotechnology (Runge and Jackson, 2000; Giannakas and Fulton, 2002; Fulton and Giannakas, 2004; Lapan and Moschini, 2004; Sheldon 2004; Noussair et al., 2004; Lusk et al., 2006; Rousu et al., 2004). A key feature of the first generation GM products is cost reduction, which has had little effect on promoting their market acceptance (Lasoued and Giannakas, 2010). The second generation GM products act as an alternative to improving market acceptance of GM products. This category included enhanced vitamin products such as vitamin A, enriched rice and maize (also known as golden rice and golden maize), high-protein wheat and high-oleic soya beans (Giannakas and Yiannaka, 2008). In contrast to the first generation GM producer oriented products, the second generation GM products were consumer oriented. The economic effects of the introduction of the second generation GM product depended mainly on the value which consumers placed on it.

However, there are also other aspects which are tied to the agricultural activities. The food system is a major contributor to global greenhouse gas (GHG) emissions. Greenhouse gases are produced at all stages in the system, from farming and its inputs through to food distribution, consumption, and the disposal of waste. Agriculture plays a significant role on the concentration of GHG emissions and consequently contributes to climate change (De Cara and Jayet, 2000). The major gases emitted by this sector are nitrous oxide (N_2O), related to fertilizer use and methane, accounting for 38% of the total GHG emissions from land usage; (CH_4) from on-farm livestock enteric fermentation and

CH_4 and N_2O from manure management accounting for 38%; CH_4 from cultivation of rice accounting for 11%, and CH_4 and N_2O from burning of savannah, forest, and agricultural residues accounting for 13% (Burney et al., 2010). It is increasingly becoming recognized that innovation and technological change will be the key determinants of climate change in the future (Christiansen, 2001). Agriculture, aside from its production purpose, contributes a significant GHG emission rate and therefore represents an appropriate arena of consideration for research.

The literature has so far treated environmentally public goods and GM products separately. The environmentally public goods are assessed using agri-environmental policy initiatives, which financially compensate the farmer for undertaking environmentally friendly practices (such as input abatement). The compensation authority is assumed to maximize social welfare, taking into account the social cost to tax payers of such schemes (Ozanne et al., 2001). The main problems arising from such schemes are due to the asymmetric information which results in the principal-agent problem (Spulber, 1988; Ozanne et al., 2001). The GM products on the other hand are treated using a consumer and producer perspective where the consumers' aversion and producers' returns are the two main drives of the product adaption (Lapan and Moschini, 1997; Giannakas and Fulton, 2002; Fulton and Giannakas, 2004).

Given the importance and the necessity of environmentally friendly actions, products, and technologies, this paper focuses on the introduction of an environmentally friendly product. The introduction of the GM product is claimed to result in a conflict between the biotech seed companies, consumers and producers (Fulton and Giannakas, 2004), and can even lower welfare due to the cost externalities associated with the labeling regime (Lapan and Moschini, 2004). The reasons for the conflict are the consumer aversion towards GM products as well as the crop's price which is sometimes set high by the innovative biotech companies. In this paper we address the economic effects of the biotechnology innovation in agriculture with particular emphasis on environmental sustainability. Given that the new GM product results in GHG emission abatement, there is a natural interest in environmental sustainability. In addition, we refer to the Kyoto protocol as the most important institution that has emerged due to the climate change (Manne and Richels, 1999) and which ensures the existence of the tradable market for GHG emissions.

To address the GHG emissions implications of the GM product innovation, we build a partial equilibrium model that captures some critical elements. The model explicitly accounts for a monopolistic innovator that sells the seeds of a new GM crop to a competitive farming industry (Moschini et al., 2000). The demand side is based on differentiated demand for the GM and conventional products, with the former being modeled as inferior quality goods (Giannakas and Fulton, 2004; Giannakas et al., 2011). There are four main parameters captured in our model which define the demand for the new GM product: (1) the consumers' aversion; (2) the productivity parameter; (3) the monopoly power and the GHG emissions market price; (4) furthermore, the analysis of the price equilibrium explicitly models the attributes of the new GM product that are necessary in order to meet the differentiated demand for GM and conventional products. We specifically use the global carbon trade as an instrument in collecting the GHG emissions abatement, which is later transferred into a farmer subsidy. An interesting feature of our setup is the possibility for no conflict at all between consumers, producers and life science companies when an environmentally GM product is introduced in a setting which provides tradable GHG emissions.

2. Background

The commercial application of GM products began in the mid-1990s. Europe's first GM product was introduced in February 1996 by the Sainsbury and Safeway stores in the United Kingdom. Later on, many agronomic improvements occurred in the crop fields (soybeans, cotton, maize and canola). The number of countries electing to grow biotech crops has increased steadily from six in 1996 (the first year of commercialization), to 18 in 2003 and 28 in 2012 (James, 2012). In 2012, hectarage of biotech crops grew at an annual rate of 6%, up by 10.3 million from 160 million hectares in 2011. The global hectarage of biotech crops grew at an annual rate of 6%, up by 10.3 million from the total area planted in 2011 with GM crops, which consisted of 160 million hectares (James, 2011). Despite the widespread use of GM products, there is a limited product combination in the market. Among the first generation technologies, only a few varieties dominate the market such as herbicide tolerant soybeans (which made up 53% of the global GM crop area in 2008, while it accounts for 70% of the worldwide soybean market), insect resistance GM maize (which accounted for 30% of the global GM area and 24% of total maize production in 2008), bollworms resistance GM cotton (which covered 7.6 million ha in India and 3.8 million in China), herbicide tolerant GM canola (which was grown mostly in Canada and United States) (Qaim, 2009). Other first generation GM products that are being developed include fungal, bacterial and virus resistant crops. GM crop technologies such as *Bacillus thuringiensis* (Bt) rice and Bt vegetables are being tested in for example Asia and Africa and are ready to be commercialized. Classified as insect, fungal, bacterial, and virus resistant, the first generation GM products are considered mainly producer oriented.

The second generation GM products, however, are consumer oriented and involve product quality improvements. Their sector placement is somewhere between the medicine and food industries. Examples of second generation GM crop are golden rice which contains some vitamin A enhancement, high oleic soybeans, high protein wheat, and high lysine corn. The second generation GM products are said to drive the first generation GM products out of the market (Giannakas and Yiannaka, 2008; Lassoued and Giannakas, 2010). However, considering the increasing population in countries such as China or India, we see the consumer oriented second generation as fulfilling a particular consumer segment's needs but not solving the problem of famine. Biotechnology also considers the environment, and not only the consumers' and producers' needs. Multifunctional agriculture captures both the social and ecological dimensions of farming, and farming is valued not only for the output production, but also for its contribution to the environment (McMichael, 2011). GM products represent a potential technology, as a response to the need for agriculture multifunctionality, combining both hunger and global warming issues. The fertilizer reduction represents an interesting and important factor due to the double effects on the production cost. At first, fertilizer as an input has a market price, and less fertilizer directly implies less production cost. Second, less fertilizer use results in GHG emission abatement, which classifies it as a social good. A single crop which embodies both aspects will result in a cheaper and less polluting product. However the monopoly rights of the biotech seed act as a price booster. As such, in response to the biotech seed monopoly pricing, we discuss carbon trade emissions. The challenge for such a crop is that the entire system needs to be involved, making the adaption process more complex but not impossible.

2.1 Feeding a growing population: issues and challenges

The considerably increasing global population brings about the problem of resource scarcity. Scientists have long warned that the population could grow faster than available resources, thereby potentially leading to famine. In order to keep up with the human population increase, commercial agriculture has been using water, fertilizer, and land both intensively (large amounts of water and fertilizer in specific areas) and extensively (on a very broad scale). The introduction of new varieties, pesticide use, fertilizer and irrigation have been key factors in doubling food production for the last 35 years (Tilman, 1999). The production of new varieties of cereals combined with increased use of fertilizers, irrigation and pesticides provided food to an expanding world population. Since their introduction in 1947, synthetic pesticides have been widely used to save crop loss due to insects, weeds and diseases. Estimates for the loss reaches billions of US dollars, previously estimated if no pesticides were used (Paoletti and Pimentel, 2000; Oerke et al., 1995), while others stress that pesticide use saves millions of tons of food and fiber every year in for example China (Huang et al., 2005). Farmers in general and in developing countries in particular tend to use intensive amounts of fertilizer, accounting for 40% of the crops' production cost (Postgate, 1998; Bock, 1984).

The use of fertilizer and pesticides is also associated with negative side effects in relation to GHG emission production. Agriculture and changes in land use have been ranked as the second largest contributor to global GHG emissions, following just behind the burning of fossil fuels to generate electricity. On average, out of the overall GHGs that came from agriculture, one third was produced from fertilizers (Stern, 2007). In the 1970s the World Health Organization (WTO) estimated that there were globally 500,000 pesticide poisonings per year resulting in 5000 deaths (Farah, 1994). However, it has been stressed that these figures should be treated with caution, since the WTO still needs to ensure accurate data (Yudelman et al., 1998). The Environmental Protection Agency (EPA) estimates that annually there are between 10,000 and 20,000 agricultural workers poisoned from pesticide use every year in USA. Environmental sustainability became a major concern following on from the substantial productivity increases. Amongst the environment problems, climate change is the largest externality and is more complex and more uncertain (Tol, 2009). Global warming in terms of the accumulation of carbon dioxide (CO_2) and other GHGs, has been extensively studied over a decade ago (Mendelsohn et al., 1994). The sources and effects of GHG emissions are more diffused than any other environmental problem. While the sources are associated with every industrial company, every farm, or even to every household, the effects are associated to agriculture, energy use, health, and many other aspects of nature (Tol, 2009).

2.2 The Kyoto Protocol

There are a number of institutions which have been created to answer the question of how and when the international community is going to deal with climate changes. The United Nation Framework Convention on Climate Change (UNFCCC) was created on 1992 and its main goal was the stabilization of the atmospheric GHGs at a sufficiently low level to prevent a dangerous anthropogenic influence on the climate. The Kyoto protocol, a binding international agreement on climate protection, was formed in 1997 (Bohringer and Vogt, 2003). It was the first agreement that established the legally binding limits for industrialized countries on emissions of carbon dioxide and other GHGs. With Russia's ratification of the protocol in 2004, the protocol went into effect in February 2005. A key aspect of the protocol is that the countries ratifying the protocol need to reduce GHGs by 5% of their 1990 level by the year 2012 (Revkin, 2001). The scheme operates by the allocation and trading of GHG emissions. One allowance gives the right to emit one ton of CO_2-equivalent. Companies that keep their emissions below the required level are allowed to trade their allowances at the price defined by the demand and supply. On the other hand, companies that have difficulties in keeping the emissions level within the allowance limits, can either choose to reduce the gas emissions by using advanced technology that reduce carbon use, or buy allowances in the market, or a combination of the two.

2.2.1 Illustrative case: China urging for CO2 emissions abatement

China's rapid economic growth has been associated with wealth and prosperity, but also serious struggles for the Chinese environment (Peters et al., 2007). Representing one of the fastest growing economies in the world, China has undergone drastic transformation with considerable improvements in people's quality of life (Ravallion and Chen, 2007). However, all of this has utilized significant amounts of resources. In 2007 China emitted 21% of the global CO_2 emissions, up from 14% in 2002 and 8% in 1981. This profligate growth has made China the largest emitter of CO_2 in the world, closely followed by USA, which is now responsible for 19% of world CO_2 emissions (Guan et al., 2009). Per capita GDP growth was the major factor in driving the increase of Chinese CO_2 emissions, while efficiency gains reduced the emissions only partly. The growth in Chinese exports will continue to be a significant source of increase in Chinese emissions. Rice for example, which has been cultivated in Asia for over 10,000 years, is the most important crop in China. China was the largest rice producer by volume in 2008 and over 90% of it was paddy rice grown in flooded fields to control weeds and vermin. It has been estimated that in rice paddies, only 30% of applied nitrogen is taken up by growing plants, approximately one third volatized as N_2O and the rest lost to runoff (Liang et al., 2007). In addition to being a major contributor to global climate change, China is also most likely to be severely affected. Thus, it is crucial for both Chinese and global climate and energy policy to understand the key driving forces of China's growing energy consumption and GHG emissions. China's national Development and Reform Commission announced that climate change would play a major role in future energy, innovation and agricultural policy. The establishment of a Clean Development Fund through a tax on certified emission reduction (CER) projects was an initiative to coordinate government and private initiatives.

3. Theoretical framework

We build a partial equilibrium model which accounts for heterogeneous demand as well as for heterogeneous producer returns between the conventional and the GM products. The two products are represented by the subscripts *c* for conventional and *gm* for GM.

3.1 Consumers' problem

To capture consumer aversion toward GM products, we model the conventional and GM counterparts as vertically differentiated goods (Noussair et al., 2004; Lusk et al., 2006; Fulton and Giannakas, 2004; Giannakas and Yannaka, 2008). That is, if offered at the same price, all consumers would choose the conventional version. In this paper we consider the same demand as Giannakas et al. (2011) and Hajderllari and Karantininis (2013), where the individual consumer has a certain utility enhancement associated with the consumption of both products. Consumer demand[1] in such settings appears as follows:

$$Y_{gm} = \frac{\lambda P_c - \mu P_{gm}}{\lambda(\mu - \lambda)} \qquad (1)$$

$$Y_c = \frac{\mu - \lambda - P_c + P_{gm}}{\mu - \lambda} \qquad (2)$$

[1] According to Giannakas et al. (2011), consumers are assumed to gain utility from consuming the GM and non GM products as well as from the substitute product, such that: $U_{gm} = U - P_{gm} + \lambda\alpha$ if a unit of the GM product is consumed, $U_{cc} = U - P_{ngm} + \mu\alpha$ if a unit of the non-GM product is consumed, and $U_s = U$ if a unit of the substitute product is consumed. U_{gm}, U_c and U_s are the utility associated with consuming a unit of GM, non-GM and the substitute unit, respectively. P_{gm} and P_{ngm} are the prices of GM and non-GM products, respectively; λ and μ capture the utility enhancement from consuming GM and non-GM foods, respectively; α captures the heterogeneity in consumer preferences. We refer to the non-GM products in Giannakas et al. (2011) as conventional in our analysis.

where P_{gm} and P_c are the prices of the GM and conventional products, respectively; λ and μ capture the utility enhancement from consuming GM and conventional foods, respectively; α captures the heterogeneity in consumer preferences. Furthermore, for the GM product in order to gain positive market share, it must be priced below the conventional counterpart (for more see Giannakas et al., 2011).

3.2 The producers' problem

In our problem the technology is embedded in the amount of fertilizer used on an annual basis as well as the seed price. The output, the amount of seeds and the price of fertilizer are assumed constant through the analysis. Consider a profit maximizing farmer that produces output y by means of two inputs, seed (S) and fertilizer (F). The two inputs take a Cobb Douglas form, $y = AS^{\gamma}F^{\beta}$, where A, γ and β are positive parameters with $\gamma + \beta < 1$ so that the production has decreasing returns to scale. The new technology is assumed to significantly reduce the quantity of fertilizer yet still produce an equivalent output to that of the conventional counterpart, due to the productivity parameter (δ) and $\delta > 1$. This leads to $Y_{gm} = \delta AS^{\gamma}F_{gm}^{\beta}$. The quantity of fertilizer used for the production of the conventional product generates pollution in the form of emissions e and $e = \frac{F}{k}$ where k is a positive parameter (see for example Amir et al., 2008).

The reduced use of fertilizer generates fewer emissions, and assuming that they are traded in a perfectly competitive trading market with price P_e, result in additional revenue for the government, which can then be transferred as a subsidy to the farmers. The reduced amount of carbon emissions is defined as:

$$\Delta e = \frac{F_c}{k} - \frac{F_{gm}}{k} \tag{3}$$

The GM product's quantity of fertilizer is defined as: $F_{gm} = \frac{F_c}{\delta}$ and captures the magnitude of the GM technology's effect on fertilizer reduction. A distinctive feature of these innovations is that they are produced mostly from R&D efforts undertaken by the private sector, and they are typically protected by intellectual property rights (IPRs), such as patents (Rausser et al., 1999). Their respective profit maximization is defined as follows:

$$\pi_c = P_c AS^{\gamma} F_c^{\beta} - s_c S_c - f_c F_c \tag{4}$$

$$\pi_{gm} = P_{gm} \delta AS^{\gamma} F_{gm}^{\beta} - s_{gm} S_{gm} - f_{gm} F_{gm} + (\frac{F_c}{k} - \frac{F_{gm}}{k}) P_e \tag{5}$$

where *P*, *s*, and *f*, represent the prices for output, seed and fertilizer, respectively. We will refer to the price of fertilizer for both products as *f*, since technology does not affect the price of fertilizer. The other parameter affected by the new technology is the seed price (*s*) which is assumed to be higher for the GM products due to patent rights. In our model we assume that $s_{gm} = s_c \mu$ where $\mu > 1$ captures the biotech seed monopoly rights.

Taking first order conditions for both products we have for the conventional:

$$FOC1: \ \gamma P_c A {S_c}^{\gamma - 1} {F_c}^{\beta} - s_c = 0 \tag{6}$$

$$FOC2: \ \beta P_c A {S_c}^{\gamma} {F_c}^{\beta - 1} - f = 0 \tag{7}$$

For the GM product we have:

$$\gamma \delta P_{gm} A S_{gm}^{\gamma - 1} \frac{F_c^{\beta}}{\delta} - s_c \mu = 0 \tag{8}$$

$$\beta \delta P_{gm} A S_{gm}^{\gamma} \frac{F_c^{\beta - 1}}{\delta} - \frac{f}{\delta} + \frac{P_e}{k} \frac{(\delta - 1)}{\delta}) = 0 \tag{9}$$

Solving equations (6) and (7) we find that:

$$S_c = \frac{A^{\frac{1}{(1-\gamma-\beta)}}\gamma^{\frac{(1-\beta)}{(1-\gamma-\beta)}}\beta^{\frac{\beta}{(1-\gamma-\beta)}}P_c^{\frac{1}{(1-\gamma-\beta)}}}{s_c^{\frac{(1-\beta)}{(1-\gamma-\beta)}}f^{\frac{\beta}{(1-\gamma-\beta)}}} \tag{10}$$

$$F_c = \frac{A^{\frac{1}{(1-\gamma-\beta)}}\gamma^{\frac{\gamma}{(1-\gamma-\beta)}}\beta^{\frac{(1-\gamma)}{(1-\gamma-\beta)}}P_c^{\frac{1}{(1-\gamma-\beta)}}}{s_c^{\frac{\gamma}{(1-\gamma-\beta)}}f^{\frac{(1-\gamma)}{(1-\gamma-\beta)}}} \tag{11}$$

$$Y_c = \frac{A^{\frac{1}{(1-\gamma-\beta)}}\gamma^{\frac{\gamma}{(1-\gamma-\beta)}}\beta^{\frac{\beta}{(1-\gamma-\beta)}}P_c^{\frac{(\gamma+\beta)}{(1-\gamma-\beta)}}}{s_c^{\frac{\gamma}{(1-\gamma-\beta)}}f^{\frac{\beta}{(1-\gamma-\beta)}}} \tag{12}$$

Solving equations (8) and (9) we get that:

$$S_{gm} = \frac{A^{\frac{1}{(1-\gamma-\beta)}}\gamma^{\frac{(1-\beta)}{(1-\gamma-\beta)}}\beta^{\frac{\beta}{(1-\gamma-\beta)}}P_{gm}^{\frac{1}{(1-\gamma-\beta)}}}{(s_c\mu)^{\frac{(1-\beta)}{(1-\gamma-\beta)}}\left[\frac{f}{\delta}-\frac{P_e}{k}\frac{(\delta-1)}{\delta}\right]^{\frac{\beta}{(1-\gamma-\beta)}}} \tag{13}$$

$$F_{gm} = \frac{A^{\frac{1}{(1-\gamma-\beta)}}\gamma^{\frac{\gamma}{(1-\gamma-\beta)}}\beta^{\frac{(1-\gamma)}{(1-\gamma-\beta)}}P_c^{\frac{1}{(1-\gamma-\beta)}}}{(s_c\mu)^{\frac{\gamma}{(1-\gamma-\beta)}}\left[\frac{f}{\delta}-\frac{P_e}{k}\frac{(\delta-1)}{\delta}\right]^{\frac{(1-\gamma)}{(1-\gamma-\beta)}}} \tag{14}$$

$$Y_{gm} = \frac{A^{\frac{1}{(1-\gamma-\beta)}}\gamma^{\frac{\gamma}{(1-\gamma-\beta)}}\beta^{\frac{\beta}{(1-\gamma-\beta)}}P_{gm}^{\frac{(\gamma+\beta)}{(1-\gamma-\beta)}}}{(s_c\mu)^{\frac{\gamma}{(1-\gamma-\beta)}}\left[\frac{f}{\delta}-\frac{P_e}{k}\frac{(\delta-1)}{\delta}\right]^{\frac{\beta}{(1-\gamma-\beta)}}} \tag{15}$$

Equations (10), (11), (13) and (14) capture the input demands for conventional and GM products respectively, while equations (12) and (15) represent the price-taker farm's supply curve. The output for the conventional product is a function of the output price, input prices and the parameters. The GM output is a function of the output price, input prices, production parameters, the carbon emission's price and the technology parameter. From equation (15) we see that:

$\frac{\Delta Y_{gm}}{\Delta \delta} > 0; \frac{\Delta Y_{gm}}{\Delta \mu} < 0; \frac{\Delta Y_{gm}}{\Delta P_e} > 0$ which implies that the higher the productivity parameter, the higher will be the GM supply; the higher the seed price of the GM, the smaller will be the GM supply; finally, the higher is P_e, the higher will be the GM supplied quantity. In our analysis we will consider the magnitude effect of the technology on both parameters' productivity and seed prices, since the carbon emission market price is exogenous.

4. The market and welfare effects of the introduction of the new GM product

In this section we capture the market effects of the introduction of the GM product. In order to define the consumer demand we use as an illustration the rice production in China which we refer to as the conventional type[2]. The average output and price for are: Y_c = 195 million mt[3], and P_c = 340 \$/mt. The estimated price elasticity for rice in China is $= \frac{\Delta Y}{\Delta P}\frac{P}{Y} = -0.589$ (Fan et al., 1994). The slope of the conventional product is defined as $b_c = \frac{\Delta P}{\Delta Y}$. We use the data to define the demand for the conventional product, where $\varepsilon = \frac{1}{b_c} * \frac{P_c}{Y_c} \rightarrow b_c = -3;\ a_c = 9.2$. We can write the inverse demand of the conventional product as:

$$P_c^D = 9.2 - 3Y_c \qquad (16)$$

From the conventional demand it is possible to derive the GM demand which is actually vertically differentiated. Since the conventional product is perceived as a higher quality product, there is an associated utility enhancement, which does not exist for the GM product. That implies a higher intersect of the conventional demand curve compared to the GM counterpart. As such, $a_c > a_{gm}$. Following the same logic the conventional product is considered as a higher quality product versus the GM counterpart, so we can say that the conventional product has a less elastic demand, while the GM product, whose consumption is based mainly on the price effect has a more elastic demand. This implies that the slope of the conventional product is higher than the GM counterpart's ($b_c > b_{gm}$). In order to capture the supply side of the product we consider the productivity parameters γ and β where $\gamma + \beta < 0$, γ=0.3 and β=0.3. The price of the seed for the conventional crop is assumed to be equal to 1; the price of the GHG emissions P_e=17.09 \$/mt CO_2; f=282 \$/mt; the productivity parameter δ and the monopoly rights parameter μ take values > 1. Below we present both graphically and numerically four different scenarios where we simulate with various values of the three key parameters such as the seed price, the productivity shifter and the global market price for carbon emissions. From equation (15) we know that the seed price goes in the opposite direction of

[2] For more information regarding the numbers, see FAOSTAT Online service (http://faostat.fao.org) and also Liang et al. (2007).

[3] mt = metric tonne, a unit of mass equal to 1 000 kilograms.

the technology and the carbon emissions market price's effect on the GM product supply. Below we present four scenarios which capture different magnitude effect of the new technology in both productivity parameter and seed price as well as carbon emission price and consumers aversion effects.

Figure 1, displays both scenario 0 and scenario I. Scenario 0 captures the baseline case where only the conventional product exists in the market and scenario. In scenario I the magnitude effect of the new technology in the productivity parameter is assumed to be higher than the magnitude effect of the new technology in the seed price while the carbon emissions price and the GM seed price are assumed constant. Above we have defined both δ and μ as greater than 1. In scenarios one we assume $\delta = 1.7$ and $\mu = 1.5$ and P_e=17.09 \$/mt CO_2. Scenario II, which captures a change in both productivity parameter and the carbon emission price while the seed price of the GM product remains constant, is displayed in Figure 2. In scenario II, we assume δ= 2 and P_e = 20 \$/mt CO_2 and μ = 1.5. Scenario III, which considers the same magnitude of change for both parameters such as, the GM seed price and the productivity parameter, while the carbon emission price remains constant, is displayed in Figure 3. In scenario II we assume δ = 1.5, Pe = 17\$/mt CO_2 and μ = 1.5.

The demand curves (D_c and D_g) and the supply curves (S_c and S_g) for the conventional and GM products are captured in Figure 1. The conventional product demand and supply as mentioned above is an illustration of the rice market in China. Furthermore point A in Figure 1 captures the rice market equilibria in China where the equilibrium price is P=340 \$/mt while the quantity Y=195 million mt.

< **Figure 1: The market and welfare effects of the introduction of the GM product** >

Before introducing the new GM product we make some simplifying assumptions. The total quantity of rice produced before and after the introduction of the GM product does not change. In addition, according to equations (1) and (2) the GM and the conventional rice are substitutes, furthermore the demand for the conventional rice as shown in the equation (2) will also depend on the substitute product's price. As such, for a low price of the GM products, the demand curve of the conventional counterpart shifts downward. Due to the aversion toward GM foods, the demand for the GM products lies below the conventional product demand curve. Before the introduction of the GM products, the market for rice is assumed to produce only conventional product, as it is shown in Figure 1 at point A, where Y_c dominates the market. Moreover, with the introduction of the GM product, the demand curve of the conventional product will shift down to D_{c1}. The new equilibrium for the conventional product is at point A_1, associated with a smaller equilibrium price (P_{c1}) and quantity (Y_{c1}). The GM market equilibrium is captured by point B which lies right behind point A and is associated with the price P_{gm} and quantity Y_{gm}. The introduction of the GM rice has shifted the production of the conventional to Y_{c1} as $Y_c = Y_{c1} + Y_{gm}$.

The consumers' and producers' welfare associated with both conventional and GM product are summarized in Table 1. It is important to emphasize that the decrease in the conventional consumers' welfare occurs mainly due to the decrease in the consumers' willingness to pay for such a product, and not due to any price increase. In such a case the only consumers who would actually lose surplus would be those who absolutely dislike GM products and would be affected by their existence on the supermarket shelves. The decrease in the conventional producers' surplus is associated with the fact that fewer producers produce the conventional product since some of them produce the GM counterpart. In Table 1, it is also shown that there is an additional value on the carbon emissions. The level of pollution is diminished by 11.05 million$ implying a potential attribute which can be associated with a higher consumer evaluation of the GM products in the real world. Below we present the values of all the potential scenarios.

<Table 1: Market, welfare and carbon emissions effects of the introduction of a GM product>

Figure 2 captures the market and welfare effects of a higher productivity parameter and/or a higher GHG emissions market price. The numerical values of this scenario are presented in Table 1 under scenario II.

< Figure 2: The market and welfare effects of a high productivity parameter and high carbon emission price>

We see from Figure 2 that a higher magnitude effect of the productivity parameter and a higher price of the carbon emissions move the market equilibria of the conventional product (A) more on the left side. The new equilibria for the conventional product A_2 is associated with a lower market quantity and a lower price. As shown in Figure 2, the conventional consumers and producers surpluses decrease as more consumers and producers shift to the consumption and production of the GM products. In addition, Table 1 shows that the higher the productivity parameter, the higher is the reduction of carbon emissions. In particular the carbon reduction can be an important explanatory factor of the downward shifting demand on the conventional. Consumers who seek for a less polluted environment would attribute a certain value to the GM consumption which does not exist on the conventional counterpart.

Lastly we capture the effect of the GM seed price on the supply curve displayed graphically in Figure 3 and numerically in Table 1 under scenario III. While the productivity parameter, which is associated with a double cost reduction, diminishes the GM supply curve slope, the seed price acts in the opposite direction. The higher the GM seed price, the steeper is the supply curve resulting on a higher market price for the GM product.

< Figure 3: Market and welfare effects of the biotech seed company´s monopoly rights>

While the seed price does not affect the conventional market, it does affect the GM market. A higher seed price is shown to shift up the GM supply curve, resulting in GM market evaporation.

As it is shown for the same or higher magnitude effect in the seed price, the GM product would be driven out of the market. Figure 3 indicates that the positive effect, which is associated with the productivity as well as with the carbon emissions price, must overcome not only the seed price effect but also consumers' aversion. Therefore, it is necessary that the productivity parameter effect is strictly higher than the seed price increase.

Besides the market effects of the GM product, the GM product introduction is associated with social aspects as well as GHG emissions due to the fertilizer shortage. In order to illustrate the effects of such a technology on the CO_2 emission abatement, we make use of the marginal abatement cost (MAC) (Amir et al., 2008).

< Figure 4: The GM product effect in the GHG emissions abatement level >

If the price was the only parameter to change, we could move along the MC_c but not actually reduce the emissions. That illustrates the fact that if the conventional crop is the only crop in the market, the carbon emission price is not an effective instrument in reducing the pollution. Figure 4 shows that the productivity parameter δ can move the MAC curve downward to MC_g. At the price P_e the benefit from innovation is captured by the area OAB, while the level of emissions emitted has moved from point A to A1. This is also represented by Δe in equation (3), defined as the difference between the existing emission levels of the conventional and the GM crops. Beside the productivity parameter the price of emissions is also shown to play a role in the level of abatement. We have specifically used the price of GHG emissions as a potential motivator toward innovation instead of a pigovian tax (see for example Bauman et al., 2008). A higher carbon market price P_e' leads to the new abatement level A_2 while the welfare will be increased by the area ABCD in addition to the area OAB.

5. Discussion

In this paper the introduction of a GM crop with multiple attributes has been analyzed. The GM product serves as an individual consumption good as well as a public good. The aim of our analysis was to be able to present such a product which offers benefits to the market as well as to society. The market effects of such a product are displayed in section 4, where we graphically illustrated each of the parameters' effects. It is important to emphasize that the market positioning of the GM product depends heavily on a) consumers' aversion, b) seed price, c) productivity parameter and d) the GHG market price. While the two parameters seed price and productivity depend on the technology associated with the biotech patent rights and R&D, the other two parameters of consumer aversion and GHG market price are exogenous.

The GHG emission market plays an important role in the adoption of such a product, since it can actually substitute the social cost of taxpayers on the implementation of environmentally schemes. Moreover, lower pollution can also serve to lower consumers' aversion toward the GM product. For countries where the pollution is a serious concern, for example in China, a product which can reduce the abatement level represents great interest. For a social optimizer aiming to maximizing society welfare, every type of technological innovation that can shift the MAC curve downward is of interest (Palmer et al., 1995; Amir et al., 2008). The price of the carbon emissions is shown to be more effective as an instrument in reducing the carbon emissions, when combined with the new technology. Since agriculture represents a serious carbon emitter we introduce such a technology in this paper and show that it has a direct effect on the carbon emission abatement level.

Consumers' aversion has long been discussed as a behavior which is hard to be changed, however there is a claim that the way the media promotes specific events or technologies affects consumers. There is evidence that the negative media coverage of biotechnology has raised public awareness, influenced public perceptions and altered the public agenda with regards to biotech foods (Kalaitzandonakes et al., 2004). Another important aspect related to consumer aversion is that it is not homogenous for all GM products. As Gaskell et al. (2003) claims, consumers are heterogeneous with respect to different applications of biotechnology. Consumers' purchasing decision will depend on the media influence as well as on the type of technology. Consumers consider GM technology on plants in a less negative way than on bacterium, animals or human genetic material (Frewer et al., 1998; Onyango and Govindasamy, 2004). In such conditions, our technology would be a less averse application with a higher adoption potential.

The adoption of the GM product is a complex process due to the many stages it has to go through and also due to heterogeneity in opinions and behaviors. Knowledge is claimed to be the singular human attribute that noticeably enhances the likelihood of GM food acceptance (Costa-Font et al., 2008). In that sense it is very important that such products are positioned correctly in the market, with all the necessary information. Moreover, the implementation of such technology requires the engagement of a regulatory organism such as government, as the one who has the authority and the power to deal with every single agent, but first and foremost with the national media and GHG global market.

6. Conclusion

This paper examined the market potential for a GM crop with multiple effects. The crop is set up to offer private producer benefits such as lower production costs, and public benefits such as less pollution. To analyze the effects of the introduction of a new crop, a model is developed which allows for heterogeneous consumer preferences as well as cost and price differences between the new crop and the existing conventional one. We show that with the adoption of the GM product, the conventional product market diminishes as the total production is assumed not to change. The graphical and numerical analyses of this paper indicate that the market adoption of the GM product depends on the magnitude effect of the four key parameters such as consumers' aversion, the seed price, the productivity increase and the GHG market price. It is shown in our analysis that consumers' aversion and the seed price affect the GM demand and consequently the supply in a negative way. On the other hand the productivity parameter and the GHG market price are shown to be positively related to the GM market. Furthermore, we show that with the introduction of the GM product, the GHG emissions are reduced, while the amount of the reduction depends on the magnitude of the productivity parameter. In particular we consider the GHG emissions reduction as a double motivator toward the GM products. At first due to the financial benefits that farmers gain when there exists a GHG emission global market. Second, the pollution reduction can be perceived as a key attribute of such a product which can reduce consumers aversion.

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Table 1: Market, welfare and carbon emissions effects of the introduction of a GM product

	Pc ($/mt)	P_{gm} ($/mt)	Yc (mill. mt)	Y_{gm} (mill. mt)	CS_c (mill. $)	CS_{gm} (mill. $)	PS_c (mill. $)	PS_{gm} (mill. $)	GHG reduced (mill. $)
Scenario 0	340	-	195	-	57,037	-	33,150	-	-
Scenario I	300	280	170	25	42,500	500	25,500	375	11.05
Scenario II	280	240	160	35	37,600	1,487.5	22,400	875	13.6
Scenario III	340	-	195	-	57,037	-	33,150	-	-

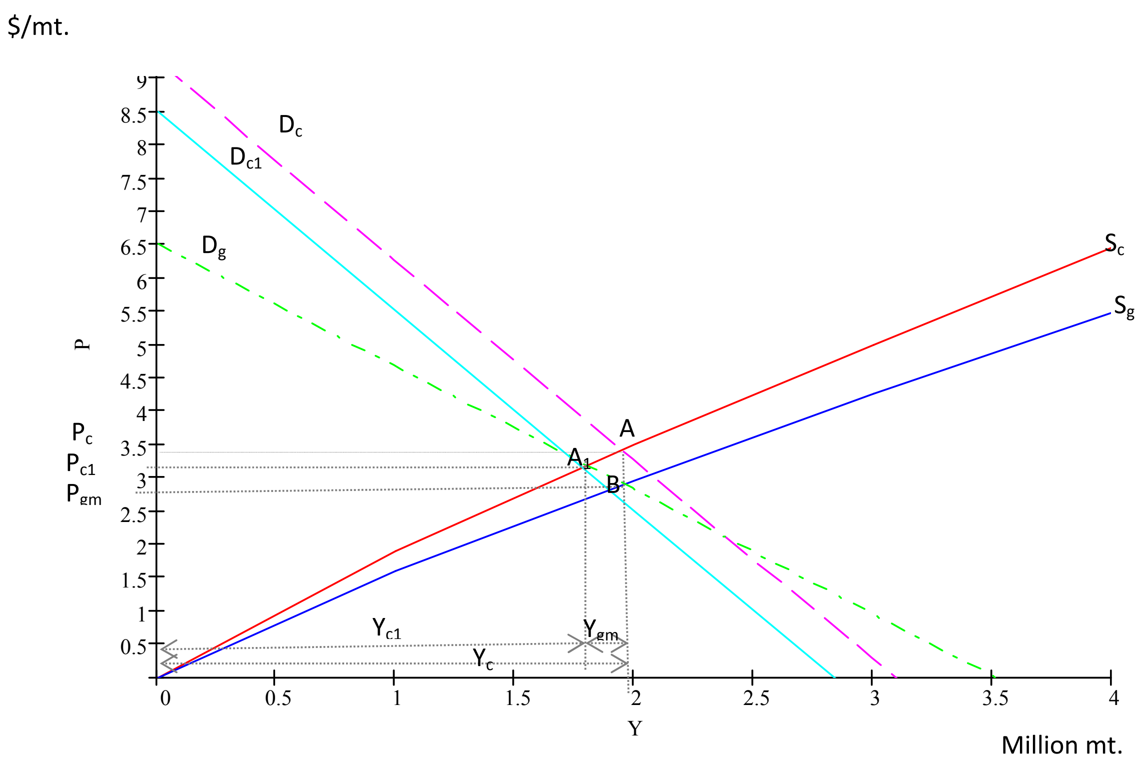

Figure 3: The market and welfare effects of the introduction of the GM product

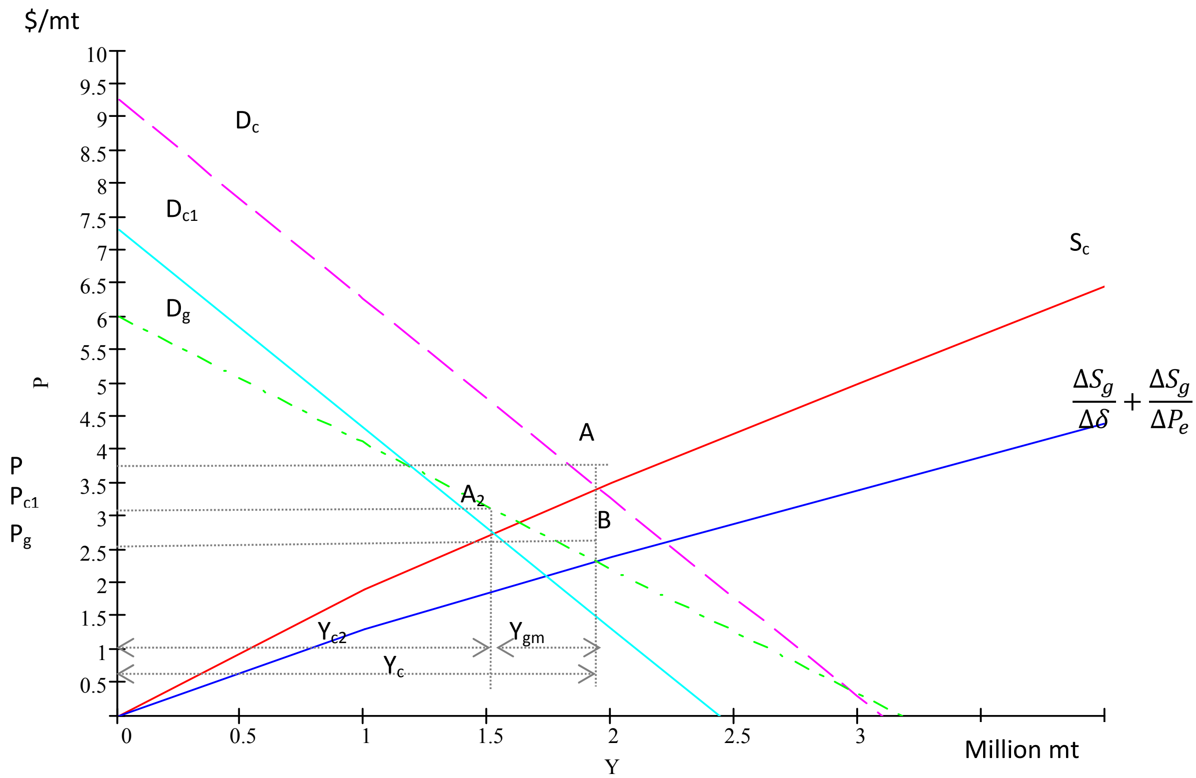

Figure 4: The market and welfare effects of a high productivity parameter and high carbon emission price

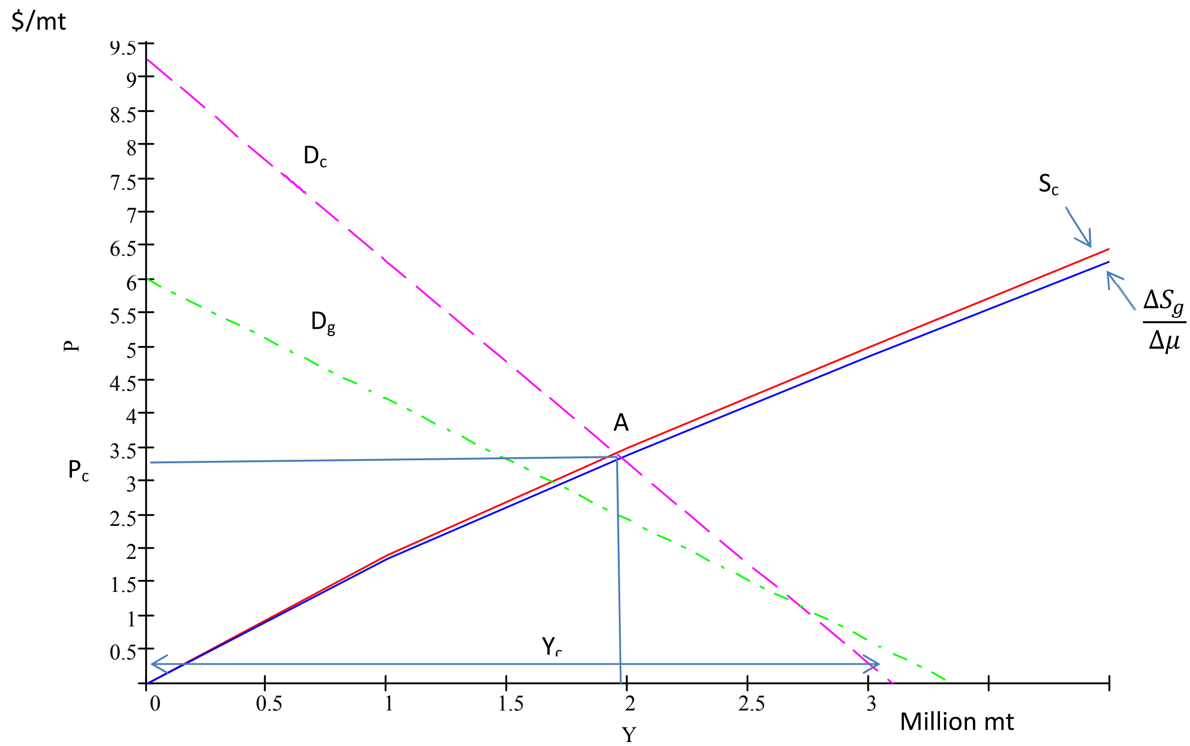

Figure 3: Market and welfare effects of the biotech seed company´s monopoly rights

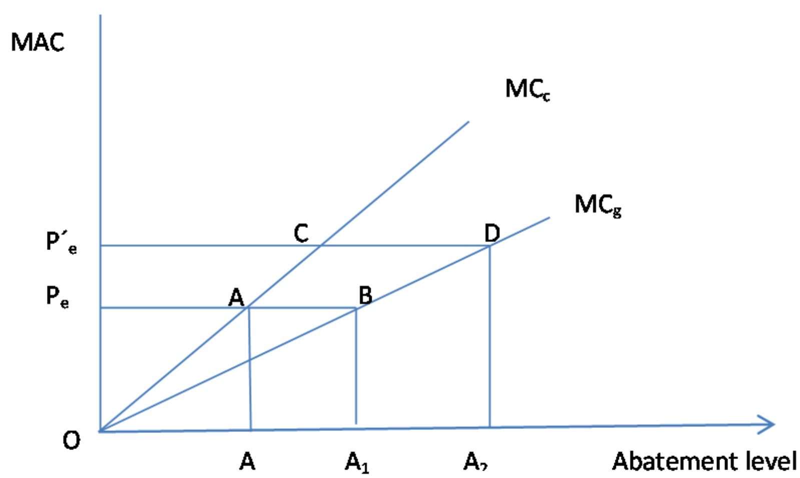

Figure 4: The GM product effect in the GHG emissions abatement level