The Coexistence of GM and non-GM crops and the Role of Consumer Preferences

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Abstract

Crop coexistence is now at the core of the debate on GM technology in Europe. New regulations are being designed in the E.U. in order to "correct" potential production externalities and ensure that conventional and organic production will remain a profitable alternative for farmers.

We use a simple Mussa-Rosen type model of preferences to capture the effects of introducing a cost-saving GM crop on incumbent crops, taking explicitly into account consumers' distaste for GM food products. Using a two-technology model, we derive necessary and sufficient conditions for coexistence and show that perfectly competitive farmers with rational expectations will adopt the socially efficient level of GM technology. We also solve a three-technology model to study the impacts of the availability of GM technology on conventional and organic production. We formally characterize the entire set of possible outcomes using only three parameters that reflect technologies' relative performance. We use our model to explore the effects of negative production externalities created by GM technology and of a change in consumers' tastes on coexistence.

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INTRODUCTION

Opposition to genetically modified organisms (GMOs) by European citizens has primarily been motivated by food safety and environmental concerns. In late 2003, the European Union (E.U.) adopted a new set of regulations pertaining to the commercialization of genetically modified (GM) food and feed. A centralized procedure for the pre-market approval of GM food and feed was instituted (European Parliament and Council, 2003). The regulations also mandate that operators adopt appropriate traceability systems to ensure that GMOs and products thereof can be identified along the food chain. In addition, new labeling rules were introduced to enable consumers to better identify food products that contain GMOs or ingredients derived from GMOs. According to the European Commission, such measures were necessary to restore consumer confidence in GM foods with the goal of enabling a viable GM crop production sector to emerge in Europe (see for instance the speech by David Byrne, European Commissioner for Health and Consumer Protection, 2001).

The next step in the European Union's efforts to induce GM crop production will be the adoption of measures pertaining to the coexistence of GM, conventional, and organic crops (European Commission, 2003). Indeed, many opponents of GMOs have argued that GM technology is not compatible with the existence of conventional and organic production sectors, since cross pollination and contamination along the food chain are likely to occur as soon as GMOs are grown on a commercial scale. Many organic and conventional producers fear that the threshold for adventitious presence of GM material in non-GM crops will be difficult to achieve, or at least that the presence of GM crops will increase their costs significantly. Organic farmers in particular would need to take additional segregation measures to avoid commingling along the food chain, if they want to supply GM-free products (i.e., products that do not contain GM material above the detection level).

Agronomic research suggests that coexistence between these technologies is feasible, but that new segregation measures, such as buffer zones or dedicated means of handling and transportation will be necessary to avoid contamination (Bock et al., 2002). Besides, the cost of segregation is likely to be higher if GM technology is widespread and if the purity level for non-GM crops is higher. Hence, adoption of GM technology by some farmers may create negative production externalities on conventional producers. At the same time, demand for non-GM foods, particularly organic products, is likely to be sensitive to the tolerance level. This suggests that organic farming could be driven out by GM technology, if consumers are unwilling to pay for high segregation costs or if their valuation for organic products decreases due to the adoption of tolerance levels.

In this paper, we develop a simple theoretical model of production and consumption of a differentiated agricultural product to give insight into the conditions under which both GM and non-GM varieties are offered in equilibrium. We formally show that whether or not all varieties coexist, the level of adoption of GM technology is socially efficient under perfect competition and in the absence of production externalities. Finally, we use our model to analyze the effects of a production externality or a change in consumers' preferences on coexistence.

REVIEW OF THE LITERATURE

Literature on the coexistence of GM and non-GM crops is recent and mostly focuses on conditions necessary to avoid commingling between GM and non GM material or to reduce it to an acceptable level. Bock et al. (2002) provide some insight into the costs associated with segregation practices in Europe for different crops. Bullock and Desquilbet (2002) examine the distribution of segregation costs along the food-processing chain for the U.S. grain market and provide quantitative measures for those costs. However, neither of those papers discusses the sustainability of one production technology by introducing demand considerations into the model. We believe nonetheless that demand is crucial in explaining the coexistence of GM and non GM technologies. As outlined by Brookes (2004), if consumers do not distinguish between GM and non GM foods, there is no coexistence issue. In this case, economic theory predicts that the cost-saving GM technology entirely replaces the existing technology. This result is certainly true if the improved technology is made available for free, as could be the case if it was the fruit of publicly-funded agricultural research. Moschini and Lapan (1997) investigate the effects of intellectual property rights (IPRs) on the adoption of a superior innovation. They show that when the improved input (such as a biotech seed) is licensed by a monopolist protected by IPRs, the monopoly prices the innovation so that adoption is complete, whether the monopolist is constrained in his pricing decision by competition with the suppliers of the old input (non drastic innovation) or not (drastic innovation). Although adoption is complete, the question of whether farmers actually gain from adopting the new technology depends on the characteristic of the innovation (drastic or non drastic) and the degree of competition among suppliers of the conventional inputs. Lapan and Moschini (2000) show that when the price of another input (say land) is endogenous to the model and is affected by adoption of the innovation, the monopolist's pricing decision might lead to incomplete adoption. In their model, the coexistence of the old and new technology does not stem from the structure of consumer preferences. It should be recognized nonetheless that consumers' perception of GM products as being of low quality compared to conventional or organic products can lead to market outcomes where coexistence is sustainable.

Consumers' distaste for GM products has been modeled by Giannakas and Fulton (2002) and Fulton and Giannakas (2004)[1]. Those authors use Mussa-Rosen (1978) preferences to analyze different policy scenarios concerning the introduction and labeling of GM foods. Throughout their analysis, they assume that whenever GM crops are allowed, coexistence between conventional and GM varieties is guaranteed. In this paper, we use a similar structure of consumer preferences but we relax the assumption of guaranteed coexistence in order to study which factors might affect coexistence in equilibrium. Lapan and Moschini (2004) study the worldwide welfare effects of segregation and traceability requirements when a GM producing country (the U.S.) does not label GM foods and an importing country (the E.U.) mandates labeling. Although their analysis has a broader scope than that of the present paper, their model does not permit a careful study of coexistence issues at the domestic level since it assumes that GM goods are produced only in the U.S. and that U.S. consumers are indifferent between GM and non-GM foods. Conversely, although European consumers care about GM foods, European farmers are only allowed to grow the conventional variety.

[1] Crespi and Marette (2003) also use Mussa-Rosen preferences to model consumers' attitudes towards GM foods. However, they do allow some consumers to be indifferent between GM and non-GM foods.

MODEL ASSUMPTIONS

Under perfect information, alternative production technologies used to produce the same product can be viewed as attributes of the product that are of different value to consumers. It can be argued that consumers value organic food more than conventional food and conventional food more than GM food. Since every consumer agrees on the relative quality of each variety (although they may differ in the intensity of their tastes), preferences would best be captured by a vertical differentiation model. We choose to specify preferences using a Mussa-Rosen (1978) model. Consumers' utilities depend on an individual parameter θ ($0<\theta<1$) and on both the quality (*s*) and price (*p*) of the consumption unit purchased, in the following fashion:

$$U_\theta(s,p)=\theta s-p\ .$$

The parameter θ is distributed uniformly on the segment $[0,1]$ and can be interpreted as the relative taste for quality. The above formulation for $U_\theta(s,p)$ implies that the reservation utility of consumers (i.e., the utility level reached if they consume no units) is zero. We will interpret quality as the level of "purity" regarding GM material.

At the production level, we assume fixed production ($Q<1$) with constant marginal cost c. However, we allow for differences in marginal costs depending on the technology used. The agricultural sector will be viewed as comprising a high number of farmers facing the same marginal costs. We will assume that farmers are profit maximizers and that they do not care about the type of technology they are using. In practice, farmers may tend to stick to a technology (an organic farmer would not shift to GM technology very easily), but from a long-run perspective our assumption is reasonable. We could imagine that farmers who do not want to shift technologies go bankrupt and are replaced by newcomers who choose the most profitable technology. Our analysis also relies on the fact that proper labeling regulations exist and are enforced, so that consumers are perfectly informed of the technology used to produce a given agricultural good.

TWO-TECHNOLOGY MODEL

To derive our first set of results, we start with a simple two-technology model that describes the effects of the availability of a new cost-saving technology, namely genetic engineering, on the production pattern of an economy with only one preexisting technology. We can think of the preexisting technology as being an average between conventional and organic production technologies. In this section, we will refer to the GM technology as technology 1 and to the conventional/organic technology as technology 2.

Starting with only technology 2 available (characterized by quality s_2 and unit cost c_2), the competitive equilibrium price is determined by the market clearing condition. Q units must be sold, $Q<1$, and the aggregate demand for the good is $1-\theta_{02}$, where θ_{02} denotes the parameter of the consumer who is indifferent between consuming and not consuming the good. Hence, we must have $Q = 1-\theta_{02} = 1-\frac{p_2^0}{s_2}$, which implies $p_2^0 = s_2(1-Q)$, where p_2^0 denotes the price of the conventional good in the initial stage, before technology 1 becomes available. The profits made by the agricultural sector are $\Pi_2^0 = (p_2^0 - c_2)Q = (s_2(1-Q)-c_2)Q$, and we will assume that these profits are positive. This means that $c_2 < s_2(1-Q)$.

Let us now introduce the GM technology, characterized by a unit cost of production c_1, with $c_1 < c_2$, and a quality level s_1, with $s_1 < s_2$. We will assume that $c_1 < s_1(1-Q)$ to ensure that the adoption of GM technology leads to positive profits. These assumptions can be justified by the fact that GM technology is cost-saving, but at the same time has lower value to consumers.

Note that since production is fixed, the choice variable for farmers is the type of technology used. Moreover, in the case where technologies do coexist, we observe two markets, one for each production technology, whereas if only one variety is produced we do not observe the price of the other variety. Let us now define precisely what we mean by a competitive equilibrium.

DEFINITION. We say that the equilibrium is competitive if one of the following conditions is satisfied.

1. Coexistence occurs and farmers maximize profits taking both prices as given.
2. Only one technology is present and the adoption of the alternative technology for an infinitesimal share of the production would not be profitable for farmers, taking the price of the existing variety as given.

This definition accounts for the fact that an increase in the share of one technology has different market implications depending on whether or not this technology is already used. If the technology is already used, an infinitesimal increase in its share of adoption will not influence the market price, whereas if it is not present a new market will appear. This difference is outlined by Hollander, Monier-Dilhan and Ossard (1999) in their study of product grading. By adopting the above definition, we implicitly assume that farmers, without having market power, can accurately foresee the price they will obtain when introducing a new variety (i.e., they form rational expectations).

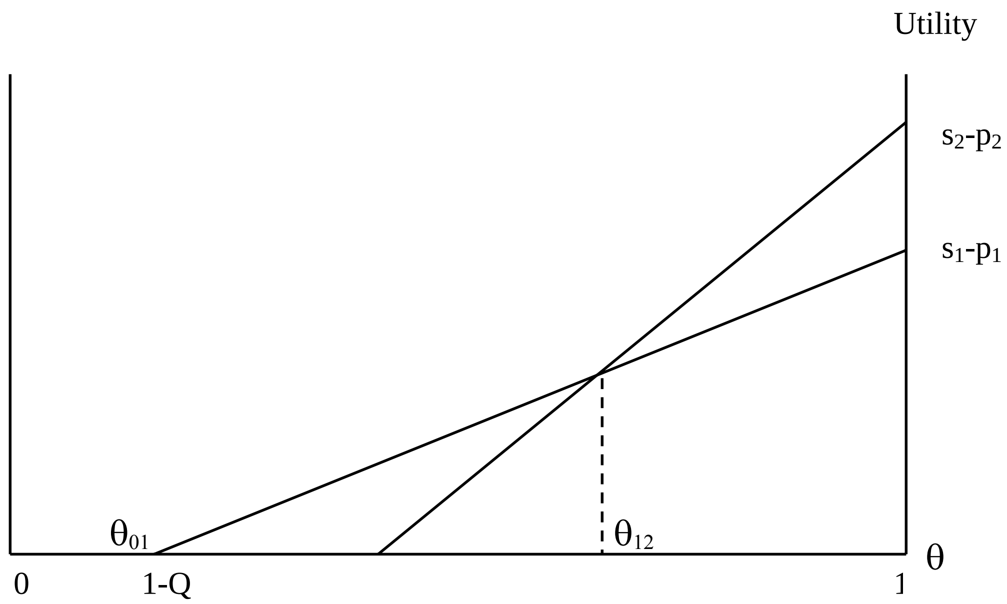

FIGURE 1. Equilibrium with coexistence of technologies 1 and 2.

Let us now consider the case where two technologies coexist under perfect competition, as illustrated in **FIGURE 1**. In **FIGURE 1**, the horizontal axis represents the taste parameter θ. θ_{01} denotes the taste parameter of the consumer who is indifferent between consuming one unit of the good obtained through technology 1 and not consuming at all, and θ_{12} denotes the taste parameter of the consumer who is indifferent between consuming one unit of the good obtained through technology 1 and one unit of the good obtained through technology 2. The vertical axis represents the utility each type of consumer obtains from each consumption option.

Since farmers take prices as given, in equilibrium the price-cost margin must be equalized between technologies. If this was not the case, farmers using the technology yielding the lower price-cost margin would have an incentive to switch technologies, which would reduce further the difference in price-cost margins. As for the one-technology case, the price of the low-quality good (here the GM good) is determined by the market clearing condition $Q = 1 - \theta_{01} = 1 - \frac{p_1^1}{s_1}$. We obtain $p_1^1 = s_1(1-Q)$, which does not depend on unit costs. Equalization of price-cost margins across technologies yields $p_2^1 = p_1^1 + c_2 - c_1 = s_1(1-Q) + c_2 - c_1$. Since $c_2 > c_1$, we have $p_2^1 > p_1^1$, i.e., the price of the conventional good is higher than that of the GM good in equilibrium.

Let us now compute the respective market shares of conventional and GM food in this competitive equilibrium. Denoting by θ_{12} the parameter of the consumer who is indifferent between the two varieties, the market shares of GM and conventional goods can be written, respectively:

$$\sigma_1 = \frac{\theta_{12} - \theta_{01}}{Q} = \frac{1}{Q}\left(\frac{p_2^1 - p_1^1}{s_2 - s_1} - \frac{p_1^1}{s_1}\right) = \frac{1}{Q}\left(\frac{c_2 - c_1}{s_2 - s_1} - 1 + Q\right) = 1 - \frac{1}{Q}\left(1 - \frac{c_2 - c_1}{s_2 - s_1}\right),$$

and $\sigma_2 = 1 - \sigma_1 = \frac{1}{Q}\left(1 - \frac{c_2 - c_1}{s_2 - s_1}\right)$.

Coexistence requires that $0 < \sigma_1 < 1$. This condition can be expressed in terms of our parameters as $1 - Q < \frac{c_2 - c_1}{s_2 - s_1} < 1$ or, defining $\lambda_{12} = \frac{c_2 - c_1}{s_2 - s_1}$, as $1 - Q < \lambda_{12} < 1$. It turns out that this condition is also sufficient for coexistence to occur.

PROPOSITION 1. *A necessary and sufficient condition for both technologies to be used in the competitive equilibrium is that* $1 - Q < \lambda_{12} < 1$.

A formal proof of **PROPOSITION 1** is given in the Appendix. We also show that if $\lambda_{12} \leq 1 - Q$, then $\sigma_1 = 0$, i.e., no farmer adopts the new technology. This could happen if

c_1 is too high or s_1 is too low, i.e., if either the new technology is not sufficiently cost-saving or it results in a very inferior quality, or both. Similarly, if $\lambda_{12} \geq 1$ then $\sigma_2 = 0$, i.e., all farmers adopt the new technology. This could be the case if biotechnology is very cost-saving or if consumers are almost indifferent about GM and conventional products. These two properties are summarized in the following propositions.

PROPOSITION 2. *If $\lambda_{12} \leq 1 - Q$, then all farmers use technology 2 in the competitive equilibrium.*

PROPOSITION 3. *If $\lambda_{12} \geq 1$, then all farmers adopt technology 1 in the competitive equilibrium.*

The above results show that coexistence of both technologies is not ensured. In particular, a high discrepancy in costs between the two technologies or the indifference of consumers to the method of production could result in the disappearance of the conventional technology. The parameter $\lambda_{12} = \dfrac{c_2 - c_1}{s_2 - s_1}$ describes the relative performance of technology 1 over technology 2. It is large when the cost of technology 1 is small relative to the cost of technology 2, and when the quality difference between technologies is not too high.

Welfare analysis

We now turn to the question of the efficiency of the competitive equilibria described above. With the specified consumer preferences, we can define consumer surplus for each consumer and add up this surplus across consumers to get total consumers' surplus. We can also add up individual farmers' profits to get the total profits of the industry. This enables us to define the total surplus of the economy as:

$$S = \int_{\theta_{01}}^{\theta_{12}} \theta s_1 d\theta + \int_{\theta_{12}}^{1} \theta s_2 d\theta - (\theta_{12} - \theta_{01})c_1 - (1 - \theta_{12})c_2 .$$

We can rewrite this as:

$$S = \frac{s_1}{2}\left[\theta_{12}^2 - \theta_{01}^2\right] + \frac{s_2}{2}\left[1 - \theta_{12}^2\right] - (\theta_{12} - \theta_{01})c_1 - (1 - \theta_{12})c_2 .$$

To find the socially efficient share for GM technology, we solve the following program:

$$\max_{\sigma_1} S \quad s.to \quad 0 \le \sigma_1 \le 1 ,$$

using the fact that $\theta_{01} = 1 - Q$ and $\theta_{12} = \sigma_1 Q + 1 - Q$ so that $\frac{\partial \theta_{01}}{\partial \sigma_1} = 0$ and $\frac{\partial \theta_{12}}{\partial \sigma_1} = Q$.

This leads to the following proposition:

PROPOSITION 4. *If* $1 - Q < \lambda_{12} < 1$*, then coexistence is socially efficient and the efficient share of technology 1 is* $\sigma_1 = 1 - \frac{1}{Q}(1 - \lambda_{12})$ *. If* $\lambda_{12} \le 1 - Q$ *, then coexistence is not socially efficient and efficiency requires that only technology 2 be used. If* $\lambda_{12} \ge 1$*, then coexistence is not socially efficient and efficiency requires that only technology 1 be used.*

Therefore, the perfectly competitive outcome is socially efficient, even when only one technology is present.

PROPOSITION 5. *Perfect competition in the production sector leads to a socially efficient level of adoption of the new technology.*

PROPOSITION 5 does not imply, however, that all agents are better off under an equilibrium with coexistence than in the initial situation. Typically, when there is coexistence, producers are better off since the price-cost margin has increased, but all consumers weakly prefer the initial situation. Consumers with $\theta < \theta_{01} = 1 - Q$ are indifferent between the two states since their utility is zero. Consumers with $\theta_{01} < \theta < \theta_{12}$ reach the utility level $U_\theta^1 = \theta s_1 - p_1^1 = \theta s_1 - s_1(1-Q)$ in the second state while they were enjoying $U_\theta^0 = \theta s_2 - p_2^0 = \theta s_2 - s_2(1-Q)$ in the first state. Since $U_\theta^1 - U_\theta^0 = (s_2 - s_1)(1 - Q - \theta)$ and $\theta > \theta_{01} = 1 - Q$, those consumers are unambiguously worse off. Finally, consumers with $\theta > \theta_{12}$ reached the utility level $U_\theta^0 = \theta s_2 - p_2^0 = \theta s_2 - s_2(1-Q)$ in the first state, and now reach $U_\theta^1 = \theta s_2 - p_2^1 = \theta s_2 - s_1(1-Q) - c_2 + c_1$. The change in their utility level is then $U_\theta^1 - U_\theta^0 = (s_2 - s_1)(1-Q) - (c_2 - c_1)$. Since coexistence requires that $1 - Q < \lambda_{12} < 1$, those consumers are also worse off. It could be shown, similarly, that when GM technology is the only technology used, producers are better off but consumers are worse off.

THREE-TECHNOLOGY MODEL

In this section, we explore the specific consequences of the availability of biotechnology on the organic sector. We will assume perfect competition among farmers, and continue to assume that farmers can switch technologies. Parameters (s_2, c_2) now refer specifically to the conventional technology (excluding the organic technology), and we introduce parameters (s_3, c_3) to characterize the organic technology, with $s_1 < s_2 < s_3$ and $c_1 < c_2 < c_3$. We will start from an initial state where conventional and organic farming are present and study the effects of the introduction of biotechnology. From the two-technology analysis, we know that a necessary (and sufficient) condition for coexistence of conventional and organic farming in the initial state is that

$1-Q < \lambda_{23} = \frac{c_3 - c_2}{s_3 - s_2} < 1$, and we will assume that this condition is satisfied. The equilibrium prices in the initial state are $p_2^0 = s_2(1-Q)$ and $p_3^0 = p_2^0 + c_3 - c_2 = s_2(1-Q) + c_3 - c_2$. The total industry profits are then $\Pi^0 = (s_2(1-Q) - c_2)Q$. We will assume that $c_2 < s_2(1-Q)$ so that farmers earn positive profits in the initial state. The shares of technology 2 and 3 in the initial state can be readily derived from the results of our two-technology model:

$$\sigma_2 = 1 - \frac{1}{Q}(1-\lambda_{23}),\ \sigma_3 = \frac{1}{Q}(1-\lambda_{23}).$$

We further assume that $c_1 < s_1(1-Q)$ to ensure that the adoption of GM technology leads to positive profits.

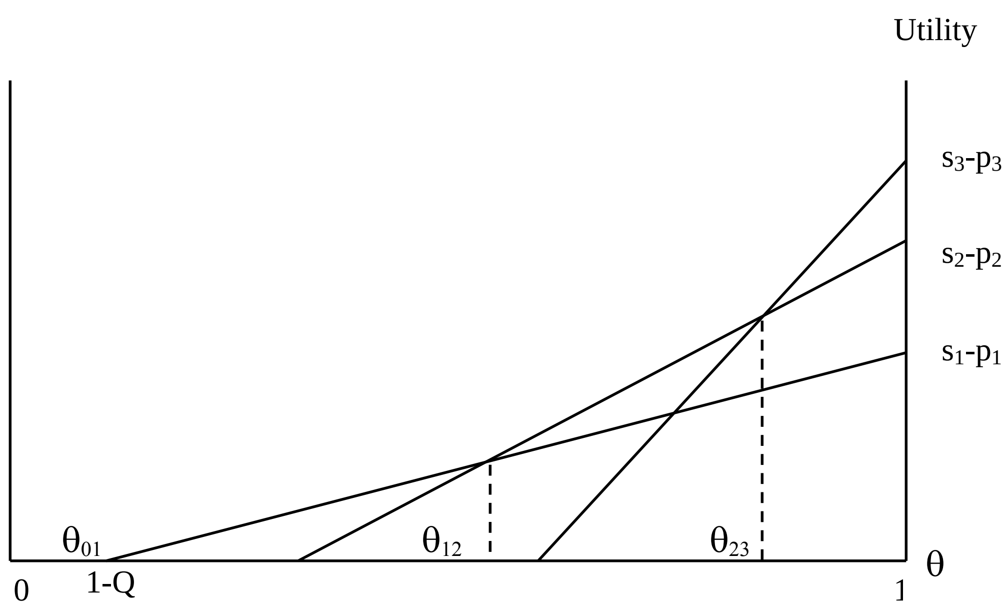

FIGURE 2. Equilibrium with coexistence of technologies 1, 2, and 3.

Under perfect competition, if the three technologies are used in equilibrium then price-cost margins must be equalized across technologies. The price of the low-quality good is determined by the market-clearing condition $Q = 1 - \theta_{01} = 1 - \frac{p_1^1}{s_1}$. Hence, we must have $p_1^1 = s_1(1-Q)$. We then obtain $p_2^1 = s_1(1-Q) + c_2 - c_1$ and $p_3^1 = s_1(1-Q) + c_3 - c_1$. The market shares σ_1, σ_2 and σ_3 are determined by the relationships $\sigma_1 Q = \theta_{12} - \theta_{01}, \sigma_2 Q = \theta_{23} - \theta_{12}$ and $\sigma_3 Q = 1 - \theta_{23}$, as illustrated in **FIGURE 2**. Since $\theta_{01} = 1 - Q$, $\theta_{12} = \frac{p_2^1 - p_1^1}{s_2 - s_1} = \frac{c_2 - c_1}{s_2 - s_1}$ and $\theta_{23} = \frac{p_3^1 - p_2^1}{s_3 - s_2} = \frac{c_3 - c_2}{s_3 - s_2}$, we have $\sigma_1 = 1 - \frac{1}{Q}\left(1 - \frac{c_2 - c_1}{s_2 - s_1}\right)$, $\sigma_2 = \frac{1}{Q}\left(\frac{c_3 - c_2}{s_3 - s_2} - \frac{c_2 - c_1}{s_2 - s_1}\right)$, and $\sigma_3 = \frac{1}{Q}\left(1 - \frac{c_3 - c_2}{s_3 - s_2}\right)$. Using the notations $\lambda_{12} = \frac{c_2 - c_1}{s_2 - s_1}$ and $\lambda_{23} = \frac{c_3 - c_2}{s_3 - s_2}$, the coexistence conditions are as follows:

$$\begin{aligned} 1 - Q &< \lambda_{12} < 1 \\ 1 - Q &< \lambda_{23} < 1 \\ 0 &< \lambda_{23} - \lambda_{12} < Q \end{aligned} .$$

The second condition ensures that the share of organic products is strictly between zero and one and this condition is satisfied since in the initial state organic farming is assumed to coexist with conventional farming. Besides, the condition $\lambda_{23} - \lambda_{12} < Q$ will automatically be satisfied as long as $1 - Q < \lambda_{12}$ and $\lambda_{23} < 1$. The above set of necessary conditions can thus be reduced to the sole condition $1 - Q < \lambda_{12} < \lambda_{23}$. It is shown in the Appendix that these conditions are also sufficient for a competitive equilibrium with coexistence of the three technologies.

PROPOSITION 6. *In the three-technology model, a necessary and sufficient condition for a competitive equilibrium with coexistence of technologies 1, 2, and 3 is that*

$1-Q<\lambda_{12}<\lambda_{23}$. *If such an equilibrium occurs, the shares of technology 1, 2, and 3 are given by* $\sigma_1=1-\frac{1}{Q}(1-\lambda_{12})$, $\sigma_2=\frac{1}{Q}(\lambda_{23}-\lambda_{12})$ *and* $\sigma_3=\frac{1}{Q}(1-\lambda_{23})$.

As a matter of fact, the entire set of market outcomes under perfect competition can be characterized in terms of the values taken by the parameters λ_{12} and λ_{13}. Those parameters reflect the performance of technology 1 relative to technologies 2 and 3, respectively. The following results are proved formally in the Appendix.

PROPOSITION 7. *If* $\lambda_{12}\le 1-Q$, *then technologies 2 and 3 are used in the competitive equilibrium and the shares of technology 2 and 3 are the same as in the initial state.*

PROPOSITION 8. *If* $\lambda_{23}\le\lambda_{12}<1$ *or* $\lambda_{12}\ge 1$ *and* $\lambda_{13}<1$, *then under perfect competition technologies 1 and 3 are used in equilibrium and the respective shares of technology 1 and 3 are* $\sigma_1^c=1-\frac{1}{Q}(1-\lambda_{13})$ *and* $\sigma_3^c=\frac{1}{Q}(1-\lambda_{13})$.

PROPOSITION 9. *If* $\lambda_{12}\ge 1$ *and* $\lambda_{13}\ge 1$, *then under perfect competition technology 1 is the only technology used.*

DISCUSSION

Let us summarize briefly the above findings. If the performance of technology 1 relative to technology 2 (as defined by the parameter λ_{12}) is too low, then technology 1 will not be used under perfect competition. Note that we do not need to make any assumptions regarding the performance of technology 1 relative to technology 3 in this case, i.e., the fact that $\lambda_{12}\le 1-Q$ suffices to infer that technology 1 will not be used.

If the performance of technology 1 relative to technology 2 and to technology 3 is high, i.e., $\lambda_{12}\ge 1$ and $\lambda_{13}\ge 1$, then technology 1 will drive out technologies 2 and 3.

Coexistence between technologies 1 and 3 will be observed in two instances: if the performance of technology 1 is high relative to technology 2 but not too high relative to technology 3, or if the performance of technology 1 relative to technology 2 is higher than the performance of technology 2 relative to technology 3.

Coexistence between the three technologies will occur when $1-Q<\lambda_{12}<\lambda_{23}$, i.e., when technology 1 performs well enough relative to technology 2, but not better than how technology 2 performs relative to technology 3. In this case, the share of organic production is the same as in the initial state. This means that the introduction of GM products will only decrease the share of conventional products.

As in the two-technology model, coexistence between technologies is not ensured. It could well be that GM technology is not adopted, either because it not sufficiently cost-saving or because consumers perceive the resulting product to be of very poor quality. On the contrary, if GM technology performs well relative to the existing technologies, it could drive out the conventional technology or even the organic technology. However, our model predicts that if the conventional variety continues to be offered in equilibrium, so does the organic variety.

Production externalities

In the above analysis, production externalities were disregarded. However, one of the main concerns about GM crops is the negative externality that they can create on conventional or organic farming. More precisely, it is argued that if GM technology is adopted, the cost of production for conventional and organic technologies could increase due additional measures taken to prevent crop contamination, and that the value of conventional and organic production could be reduced due to the adoption of tolerance levels for the adventitious presence of GM material. Both effects are likely to increase with the share of GM technology used in the agricultural sector.

In terms of our three-technology model, we can think of these production externalities as an increase in c_2 and c_3 and a decrease in s_2 and s_3. This implies an increase in both λ_{12} and λ_{13}, while the effect on λ_{23} is ambiguous. For the sake of simplicity, we will assume that the production externalities only affect the organic sector. This could be the case if the tolerance level for conventional products has been set high enough so that no costly measure is necessary to prevent contamination, and if consumers do not discount the quality of conventional products when they satisfy the regulatory threshold. As a result, we will observe an increase in λ_{13} and λ_{23}, while λ_{12} will remain unchanged.

If the three technologies coexist in equilibrium, the effect of the production externality will be to reduce the share of organic production to the benefit of the conventional sector. Similarly, if GM technology coexists with organic technology, the effect of the externality will be to reduce the share of organic production. Finally, since λ_{13} increases, the outcome where GM technology is the only technology used in equilibrium will be more likely to occur.

The evolution of consumers' perceptions

Our three-technology model can also be used to study the evolution of the three markets as consumers become indifferent to GM, starting from an initial situation where $\lambda_{12} \leq 1 - Q$. We believe that this assumption is plausible for Europe even if consumers are currently opposed to GM technology. As suggested in a recent study by Noussair, Robin, and Ruffieux (2004) based on experimental economics techniques, European consumers might not be as reluctant to consume GM products as outlined in the previous literature. Besides, as stated in the introduction, one of the main justifications the European Commission gave for the new GM legislation is that stringent rules would restore consumer confidence in GM products, thus allowing a market for GM foods to emerge.

For the purpose of this analysis, we neglect any production externality. Let us assume that the parameter s_1 increases, starting from a value small enough for the condition $\lambda_{12} \leq 1-Q$ to hold. An increase in s_1 will increase λ_{12} and λ_{13} but will not affect λ_{23}. As s_1 increases, we will have $1-Q < \lambda_{12} < \lambda_{23}$, i.e., GM technology will be adopted. As s_1 continues to increase, the share of GM technology will increase at the expense of conventional technology, but the share of organic technology will remain unaffected as long as conventional technology is used. When $\lambda_{23} \leq \lambda_{12} < 1$, conventional technology is no longer used and as s_1 increases, the share of GM technology continues to grow at the expense of organic technology. When $\lambda_{12} \geq 1$, the outcome will depend on the value of λ_{13}. If $\lambda_{13} < 1$, then organic and GM technologies will continue to coexist. Coexistence will be guaranteed even when s_1 gets arbitrarily close to s_2, provided that $\frac{c_3 - c_1}{s_3 - s_2} < 1$. Otherwise, organic technology will disappear if s_1 gets close enough to s_2.

CONCLUSION

The adoption of GM crop technology remains a controversial issue in Europe. The new regulatory framework for the commercialization of GM food and feed in the E.U. has brought many issues to the forefront, including questions related to the coexistence of GM and other crops. Concerns have been expressed that costs would rise for conventional and organic farmers due to required segregation. Current regulatory proposals in several E.U. member states are designed to try and ensure coexistence among GM, conventional and organic production.

In this paper, we have used a simple Mussa-Rosen type model of preferences to capture the effects of introducing a cost-saving GM crop on incumbent crops, taking explicitly into account consumers' distaste for GM food products. Using a two-technology model, we derived necessary and sufficient conditions for coexistence and showed that perfectly competitive farmers with rational expectations would adopt the socially efficient level of GM technology. We then solved a three-technology model to study the impacts of the availability of GM technology on conventional and organic production. We formally characterized the entire set of possible outcomes using only three parameters that reflect technologies' relative performance. In the absence of any production externality, we showed that if conventional and organic production technologies coexist in the initial state, then the introduction of GM technology could result in coexistence of the three technologies, disappearance of the conventional sector, or disappearance of both the conventional and organic sectors.

We used our model to explore the effects of negative production externalities created by GM technology on the organic sector, and found evidence that such production externalities would reduce the share of organic in the crop mix compared to the case where no production externality exists. We also found that externalities could precipitate the disappearance of the organic sector in cases where the conventional sector has already disappeared.

Finally, we studied the effect of a change in consumers' perception of GM products, and showed that as consumers become indifferent between GM and conventional products, conventional technology is abandoned. In some cases, organic production could disappear as well.

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APPENDIX

Proof of **PROPOSITION 1**

Suppose that $1-Q<\lambda_{12}<1$. Firstly, suppose that in equilibrium only technology 2 is used. If technology 1 was used for an infinitesimal share of total production, the resulting price-cost margin would be $s_1(1-Q)-c_1$ instead of $s_2(1-Q)-c_2$. Since by assumption $1-Q<\lambda_{12}$, it would be profitable. Hence we cannot have a competitive equilibrium with only technology 2. Secondly, suppose that in equilibrium only technology 1 is used. If technology 2 was used for an infinitesimal share of total production, the resulting price would solve $\theta_{12}=\dfrac{p_2-p_1}{s_2-s_1}=1$, i.e., we would have $p_2=s_1(1-Q)+s_2-s_1$. The resulting price-cost margin would be $s_1(1-Q)+s_2-s_1-c_2$ instead of $s_1(1-Q)-c_1$. Since $\lambda_{12}<1$, this would be profitable. Hence we cannot have a competitive equilibrium with only technology 1. Therefore the only possible market outcome involves coexistence of technologies 1 and 2.

Proof of **PROPOSITION 2**

Suppose that $\lambda_{12} \leq 1-Q$. Firstly, note that from **PROPOSITION 1**, an equilibrium with coexistence cannot occur, since a necessary condition for this would be that $1-Q < \lambda_{12} < 1$. Hence, suppose that in equilibrium only technology 1 is used. If technology 2 was used for an infinitesimal share of total production, the resulting price would solve $\theta_{12} = \frac{p_2 - p_1}{s_2 - s_1} = 1$, i.e., we would have $p_2 = s_1(1-Q) + s_2 - s_1$. The resulting price-cost margin would be $s_1(1-Q) + s_2 - s_1 - c_2$ instead of $s_1(1-Q) - c_1$. Since $\lambda_{12} \leq 1-Q < 1$, this would be profitable. Hence we cannot have a competitive equilibrium with only technology 1. Therefore the competitive equilibrium involves only technology 2.

Proof of **PROPOSITION 3**

Suppose $\lambda_{12} \geq 1$. Firstly, note that from **PROPOSITION 1**, an equilibrium with coexistence cannot occur. Hence, suppose that in equilibrium only technology 2 is used. If technology 1 was used for an infinitesimal share of total production, the resulting price-cost margin would be $s_1(1-Q) - c_1$ instead of $s_2(1-Q) - c_2$. Since $\lambda_{12} \geq 1 > 1-Q$, this would be profitable. Hence we cannot have a competitive equilibrium with only technology 2. Therefore the competitive equilibrium involves only technology 1.

LEMMA. *In the three-technology model, if technologies 2 and 3 coexist in the initial state, then an equilibrium with coexistence of technologies 1 and 2 cannot occur.*

Proof of **LEMMA**

Suppose that we have an equilibrium with only technologies 1 and 2. If technology 3 was used for an infinitesimal share of total production, the resulting price would solve

$\theta_{23} = \dfrac{p_3 - p_2}{s_3 - s_2} = 1$, i.e., we would have $p_3 = p_2 + s_3 - s_2 = s_1(1-Q) + c_2 - c_1 + s_3 - s_2$. The resulting price-cost margin would be $p_3 - c_3 = s_1(1-Q) + c_2 - c_1 + s_3 - s_2 - c_3$ instead of $s_1(1-Q) - c_1$. Since coexistence of technologies 2 and 3 in the initial state requires in particular that $\lambda_{23} < 1$, this move would be profitable. Hence an equilibrium with coexistence of technologies 1 and 2 cannot occur.

Proof of **PROPOSITION 6**

Suppose that $1 - Q < \lambda_{12} < \lambda_{23}$. Firstly, note that market outcomes involving only technology 2 or only technology 3 cannot occur, since in the initial situation technology 2 and 3 coexist. Besides, the above **LEMMA** rules out coexistence of technologies 1 and 2. So the possible market outcomes are: coexistence of technologies 1, 2, and 3; coexistence of technologies 2 and 3; coexistence of technologies 1 and 3; only technology 1.

Suppose that in equilibrium only technologies 2 and 3 are used. If technology 1 was used for an infinitesimal share of total production, the resulting price-cost margin would be $s_1(1-Q) - c_1$ instead of $s_2(1-Q) - c_2$. Since by assumption $\lambda_{12} > 1 - Q$, this would be profitable. Hence we cannot have a competitive equilibrium with only technology 2.

Suppose that in equilibrium only technologies 1 and 3 are used. If technology 2 was used for an infinitesimal share of total production, the resulting price would solve $\theta_{12} - \theta_{23} = \dfrac{p_2 - p_1}{s_2 - s_1} - \dfrac{p_3 - p_2}{s_3 - s_2} = 0$. Using the fact that $p_1 = s_1(1-Q)$ and $p_3 = s_1(1-Q) + c_3 - c_1$, this gives $p_2 = s_1(1-Q) + \lambda_{13}(s_2 - s_1)$. The resulting price-cost margin would then be $s_1(1-Q) + \lambda_{13}(s_2 - s_1) - c_2$ instead of $s_1(1-Q) - c_1$. Hence, this move would be profitable if and only if $\lambda_{13} > \lambda_{12}$, which can be shown to be equivalent to

$\lambda_{23} > \lambda_{12}$. Since by assumption $\lambda_{12} < \lambda_{23}$, we can conclude that the introduction of technology 2 would be profitable, and thus that there cannot be an equilibrium with technologies 1 and 3.

Suppose that only technology 1 is used in equilibrium. If technology 2 was used for an infinitesimal share of total production, the resulting price would solve $\theta_{12} = \frac{p_2 - p_1}{s_2 - s_1} = 1$, i.e., we would have $p_2 = s_1(1-Q) + s_2 - s_1$. The resulting price-cost margin would be $s_1(1-Q) + s_2 - s_1 - c_2$ instead of $s_1(1-Q) - c_1$. Since by assumption $\lambda_{12} < \lambda_{23} < 1$, this would be profitable. Hence we cannot have a competitive equilibrium with only technology 1.

We have proved that the only possible outcome is an equilibrium with coexistence of the three technologies.

Proof of **PROPOSITION 7**

Suppose $\lambda_{12} \leq 1 - Q$. Firstly, note that the following cases cannot occur: coexistence of the three technologies (from **PROPOSITION 6**), coexistence of technologies 1 and 2 (from **LEMMA**), only technology 2 or only technology 3 (from the initial state). The equilibrium can either involve technologies 2 and 3, technologies 1 and 3, or only technology 1.

Suppose that in equilibrium only technology 1 is used. If technology 2 was used for an infinitesimal share of total production, the resulting price would solve $\theta_{12} = \frac{p_2 - p_1}{s_2 - s_1} = 1$, i.e., we would have $p_2 = s_1(1-Q) + s_2 - s_1$. The resulting price-cost margin would be $s_1(1-Q) + s_2 - s_1 - c_2$ instead of $s_1(1-Q) - c_1$. Since $\lambda_{12} \leq 1 - Q < 1$, this would be profitable. Hence we cannot have a competitive equilibrium with only technology 1.

Suppose that in equilibrium technologies 1 and 3 coexist, and suppose that technology 2 is used for an infinitesimal share of the production. By the same reasoning, we can conclude that this move would be profitable.

Therefore, the only possible equilibrium is to have coexistence between technologies 2 and 3.

Proof of **PROPOSITION 8**

Suppose first that $\lambda_{23} \leq \lambda_{12} < 1$. Given **PROPOSITION 6**, the **LEMMA** and the initial state, the equilibrium can either involve technologies 2 and 3, technologies 1 and 3, or only technology 1.

Suppose that the equilibrium involves technologies 2 and 3. If technology 1 was used for an infinitesimal share of total production, the resulting price-cost margin would be $s_1(1-Q)-c_1$ instead of $s_2(1-Q)-c_2$. Since by assumption $1-Q < \lambda_{23} \leq \lambda_{12}$, this would be profitable. Hence we cannot have a competitive equilibrium with technologies 2 and 3.

Suppose that the equilibrium involves only technology 1, and let us introduce technology 2 for an infinitesimal share of the production. The resulting price would solve $\theta_{12} = \dfrac{p_2 - p_1}{s_2 - s_1} = 1$, i.e., we would have $p_2 = s_1(1-Q)+s_2-s_1$. The resulting price-cost margin would be $s_1(1-Q)+s_2-s_1-c_2$ instead of $s_1(1-Q)-c_1$. Since by assumption $\lambda_{12} < 1$, this move would be profitable.

Hence the only possible equilibrium is coexistence between technologies 1 and 3.

Suppose now that $\lambda_{12} \geq 1$ and $\lambda_{13} < 1$. As before, the equilibrium can either involve technologies 2 and 3, technologies 1 and 3, or only technology 1.

Suppose that the equilibrium involves technologies 2 and 3. If technology 1 was used for an infinitesimal share of total production, the resulting price-cost margin would be $s_1(1-Q)-c_1$ instead of $s_2(1-Q)-c_2$. Since by assumption $\lambda_{12} \geq 1 > 1-Q$, this would be profitable. Hence we cannot have a competitive equilibrium with technologies 2 and 3.

Suppose that the equilibrium involves only technology 1, and let us introduce technology 3 for an infinitesimal share of the production. The resulting price would solve $\theta_{13} = \frac{p_3 - p_1}{s_3 - s_1} = 1$, i.e., we would have $p_3 = s_1(1-Q) + s_3 - s_1$. The resulting price-cost margin would be $s_1(1-Q) + s_3 - s_1 - c_3$ instead of $s_1(1-Q) - c_1$. Since by assumption $\lambda_{13} < 1$, this move would be profitable.

Hence the only possible equilibrium is coexistence between technologies 1 and 3.

Proof of **PROPOSITION 9**

Suppose $\lambda_{12} \geq 1$ and $\lambda_{13} \geq 1$. Given **PROPOSITION 6**, the **LEMMA** and the initial state, the equilibrium can either involve technologies 2 and 3, technologies 1 and 3, or only technology 1.

Suppose that in equilibrium technologies 2 and 3 coexist, and let us introduce technology 1 for an infinitesimal share of the production. The resulting price-cost margin would be $s_1(1-Q)-c_1$ instead of $s_2(1-Q)-c_2$. Since by assumption $\lambda_{12} \geq 1 > 1-Q$, this would be profitable. Hence we cannot have a competitive equilibrium with technologies 2 and 3.

Suppose that in equilibrium technologies 1 and 3 coexist. From **PROPOSITION 1**, we must have $1-Q < \lambda_{13} < 1$, which contradicts our assumption that $\lambda_{13} \geq 1$.

So the only possible equilibrium involves only technology 1.