

In medio stat virtus: coexistence policies for GM and non-GM production in spatial equilibrium

GianCarlo Moschini*

Iowa State University, USA

Received May 2014; final version accepted December 2014

Review coordinated by Steve McCorrison

Abstract

This article develops a spatial equilibrium model suitable to analyse the economic impacts of measures (such as isolation distances and buffer zones) meant to ensure coexistence between genetically modified (GM) and non-GM crops. We show that policies that put the cost of such measures exclusively on GM producers lead to a competitive equilibrium that is biased against GM products (relative to the welfare maximising allocation). Efficient allocation is restored if the cost of implementing coexistence measures is shared equally between adjacent GM and non-GM farms.

Keywords: biotechnology, externality, nonconvexity, regulation, welfare

JEL classification: Q18

1. Introduction

Since becoming commercially available in 1996, genetically modified (GM) crops have been both successful and controversial. In 2013, more than 175 million hectares of GM crops were grown worldwide (James, 2013). Production is, however, geographically concentrated into five main countries (United States, Argentina, Brazil, India and Canada), which together accounted for nearly 90 per cent of the area planted to GM crops in 2013. Remarkably, for a large agricultural producing region, the European Union (EU) has been on the sidelines. In 2013, when the United States planted 70.1 million hectares to GM crops, for example, the EU only grew about 0.1 million hectares (all of it maize, and most of which was grown in one country, Spain). This state of affairs reflects the contentious reception of agricultural biotechnology by some segments of the public, and the related stringent regulation for GM

*Corresponding author: E-mail: moschini@iastate.edu

crops. Indeed, the EU arguably has the most comprehensive and restrictive GM product regulation in the world.

The terms of the EU regulation of GM products includes three main pillars. First, a pre-market authorisation that hinges on a single risk assessment process by the European Food Safety Authority, and a multi-level risk management stage that involves both the Commission and the member states. Next, post-market obligations include two distinct sets of measures: comprehensive mandatory GM product labelling and traceability requirements, which became operative in April 2004; and, a set of ‘coexistence measures’ as articulated in the July 2010 Recommendation 2010/C 200/01 ‘on guidelines for the development of national co-existence measures to avoid the unintended presence of GMOs in conventional and organic crops’ (European Commission, 2010). This recommendation repealed and replaced the earlier July 2003 Recommendation 2003/556/EC that first set out guidelines for strategies and best practices for coexistence.

The stated intention of coexistence measures is to address economic and marketing implications, not safety issues (which are assumed to have been dealt with satisfactorily at the pre-market GM approval stage). The main concern being addressed is adventitious contamination at the farm level as may arise from using impure seed lots, cross-pollination and/or sharing of harvesting machinery. Thus, what coexistence rules are trying to address is a type of externality that GM growers may impose on non-GM farmers. Because this EU regulation is being handled through the principle of subsidiarity, specific measures are being worked out at the national level. Coexistence measures being contemplated include spatial isolation, such as mandatory isolation distances between GM and non-GM plots and/or the use of buffer zones, and time isolation (Czarnak-Klos and Rodriguez-Cerezo, 2010). Such requirements are non-trivial. For example, isolation distances being considered by EU states for maize range from 15 to 800 m, with a median of 200 m (Devos, Dillen and Demont, 2014).¹

A key principle articulated in Recommendation 2003/556/EC was that farmers ‘who introduce the new production type should bear the responsibility of implementing the farm management measures necessary to limit gene flow’ (European Commission, 2003). This clearly entailed a strong assignment of property rights, suggesting the implementation of procedures based on the often-invoked polluter-pays principle. The currently active Recommendation 2010/C 200/01 moved away from such an explicit assignment of property rights, providing flexibility to member states to tailor coexistence measures to

1 Concerns about coexistence are not unique to the EU, see, for example, Furtan, Güzel and Weseen (2007), and Green and Smith (2010). In the United States, in 2011 the US Secretary of Agriculture reactivated the Advisory Committee on Biotechnology and 21st Century Agriculture (AC21) and charged it to focus on issues related to the coexistence of biotech, organic and conventional crops. The ensuing report (AC21, 2012) addressed potential compensation mechanisms to deal with losses to farmers due to unintended presence of GM material, although it did not come to a consensus on that matter.

their specific needs.² This observation motivates the analysis of this article. Given that coexistence measures are implemented to avoid unintended GM presence in conventional and organic production, does it matter whose burden it is to implement such measures?

To address this question, we develop a simple but explicit spatial equilibrium model that captures some of the essential aspects of the coexistence problem. Our approach is novel relative to the existing literature in a few key dimensions. Beckmann, Soregaroli and Wessler (2006, 2011) focussed on the trade-off between *ex ante* regulations (such as isolation distances and buffer zones) and *ex post* liability rules (defining compensation for possible economic damage suffered by non-GM producers). Demont *et al.* (2008, 2009) and Ceddia *et al.* (2011) compared the effects of alternative coexistence measures in an explicit spatial context using simulation methods. As noted by Desquilbet and Poret (2013), a limitation of all such contributions is that the prices of GM and non-GM products are taken as exogenous (i.e. they are not equilibrium analyses). Desquilbet and Poret (2014) developed an equilibrium model of coexistence within a vertical product differentiation (VPD) model and used it to study the effects of *ex ante* regulation and *ex post* liability on market outcomes and welfare. Their equilibrium model, however, is non-spatial in nature. The equilibrium model we develop in this article, by contrast, captures the essential spatial nature of coexistence measures such as isolation distances and buffer zones. This approach also permits us to emphasise the fact that the externality effect noted by previous coexistence studies is best viewed as a nonconvexity, with specific implications for equilibrium and welfare.

This article is organised as follows. Section 2 provides the details of the demand side, which presumes that consumers weakly prefer non-GM product to GM-product in a VPD structure, and of the supply side, where coexistence measures are implemented by GM producers. Section 3 characterises competitive equilibria. Section 4 exploits the equilibrium nature of the model to derive the welfare implications of the analysis. Section 5 discusses possible effects of farmers' negotiations on the competitive equilibrium. The article concludes with further discussion of the model and its policy implications.

2. The model

Although the first-generation GM crops have featured agronomic traits intended to increase production efficiency – such as herbicide tolerance and insect resistance – a by-product of their introduction has been an induced product differentiation effect on the demand side (Moschini, 2008). Specifically, insofar as some consumers are averse to GM products and they are willing to pay a premium to avoid them, the post-innovation market is best viewed as one with VPD

2 But the new Recommendation 2010/C 200/01 opens the door for even more stringent coexistence measures by noting that the potential loss of income for conventional and organic producers may arise even if the adventitious presence of GM material does not reach the 0.9 threshold that triggers mandatory GM labelling.

preferences. To supply all segments of the market, a costly system of segregation and identity preservation is required (Desquilbet and Bullock, 2009), a process that encompasses the coexistence measures analysed in this article. In the model that we develop, therefore, we postulate a VPD demand structure. On the supply side, we assume profit maximising agents that choose between conventional production and a more efficient GM technology. Because our focus is on coexistence measures at the farm level (isolation distances and/or buffer zones), we abstract from other measures required to maintain identity preservation throughout the processing and distribution system. The model we propose is also simplified in other respects. Unlike other contributions in the field (Beckmann, Soregaroli and Wessler, 2006; Desquilbet and Poret, 2014), we do not model explicitly liability provisions. In some sense, however, such rules are implicit in our model: we do assume that farmers comply with the mandated coexistence measures, which in turn presumes the existence of an effective enforcement system (and liability rules could clearly serve that purpose).

2.1. Demand: VPD

As noted, the presumption is that consumers view otherwise-identical GM and non-GM products within the VPD preference structure. Specifically, we employ the simple unit-demand parameterisation of the VPD model of Mussa and Rosen (1978), whereby each consumer buys at most one unit of the good in question and her preferences are described by the (indirect) utility function $U = \theta\tilde{q} - p$ (if the good is bought, $U = 0$ otherwise), where $\tilde{q} \in \mathbb{R}_{++}$ indexes the quality of the good, $p \in \mathbb{R}_{++}$ is the price of the good and the preference parameter $\theta \in [\underline{\theta}, \bar{\theta}] \subseteq \mathbb{R}_+$ indexes consumer types. The hypothesis here is that of heterogeneous preferences for quality so that the population of consumers can be characterised by the distribution function $G(\theta)$ of the preference parameter.

More specifically, in our context there are only two possible qualities in this market, a ‘low’ quality q_g (the GM product) and a ‘high’ quality $q_n > q_g$ (the non-GM product). If these two qualities are available at prices p_g and p_n , respectively, where $p_n > p_g > 0$, then the consumer decision problem is to select the choice that yields the highest utility among the three possible options

$$U = \begin{cases} \theta q_n - p_n & \text{if the non-GM product is bought} \\ \theta q_g - p_g & \text{if the GM product is bought} \\ 0 & \text{otherwise} \end{cases} . \quad (1)$$

We further postulate that the distribution $G(\theta)$ is uniform and that $\theta \in [0, 1]$. The latter condition, in particular, implies that the market will be ‘uncovered’ (i.e. as long as prices are strictly positive, some consumers with a low enough θ will not buy anything).

To derive the demand functions implied by these preferences, define the threshold levels $\hat{\theta} \equiv (p_n - p_g)/(q_n - q_g)$ and $\theta_0 \equiv p_g/q_g$. Throughout, we will consider the typical case where $0 < \theta_0 \leq \hat{\theta} \leq 1$, such that consumers with $\theta \in [\hat{\theta}, 1]$ will buy the non-GM product, consumers with $\theta \in [\theta_0, \hat{\theta}]$ will buy the GM

product and consumers with $\theta \in [0, \theta_0]$ will buy nothing. For the population of M consumers, market demands are readily obtained by integrating the unit demand of each consumer given the distribution of consumer types. For the uniform distribution invoked earlier, the aggregate market demand functions are

$$X_n^D = M \left(1 - \frac{p_n - p_g}{q_n - q_g} \right), \quad (2)$$

$$X_g^D = M \left(\frac{p_n - p_g}{q_n - q_g} - \frac{p_g}{q_g} \right). \quad (3)$$

In what follows it is convenient to work with the inverse demand functions. To simplify notation somewhat, define $q_g \equiv q$ and $q_n \equiv q + a$, so that $a = q_n - q_g > 0$ is the ‘additional’ quality provided by the non-GM product for the highest-value consumer. Inverting Equations (2) and (3), for given quantities $\{X_i \in [0, M], i \in \{g, n\}\}$, satisfying $X_g + X_n \leq M$, yields

$$p_g = q \left(1 - \frac{X_g + X_n}{M} \right), \quad (4)$$

$$p_n = (q + a) - \frac{(qX_g + (q + a)X_n)}{M}. \quad (5)$$

Equations (4) and (5) display the market’s marginal willingness to pay for the two goods, for given supply levels, but also implicitly defines the marginal willingness to pay for the additional quality associated with the non-GM product, which is parameterised by a . It follows that the (inverse) derived demand for the additional quality is

$$p_n - p_g = a \left(1 - \frac{X_n}{M} \right). \quad (6)$$

Note that this (market) marginal willingness to pay for the additional quality depends only on the quantity supplied of the high-quality good (because this quantity implicitly defines the marginal consumer who is indifferent between purchasing the non-GM or GM good).

2.2. Coexistence measures and supply

We suppose a large number N of farms, and for simplicity we assume that they are identical, with size normalised to one, and that they each have the same expected output y . To motivate the potential adoption of GM crops, given that they are considered weakly inferior on the demand side, we need to postulate some efficiency advantage. GM crops with herbicide tolerance traits provide cost savings relative to conventional crops, whereas GM crops with insect-resistant traits, in addition to cost savings, are believed to also have a yield-enhancing effect (Xu *et al.*, 2013). For the purpose of this article, however, the higher efficiency of GM crops is

modelled simply as a cost-saving effect. This approach permits a cleaner analytical solution because, given that total land is constant, it keeps total output fixed. Consequently, we can focus on how coexistence measures affect the allocation of land between GM and non-GM crops without having to deal with the possible aggregate output change from GM crop adoption that would arise if the efficiency gain of GM crops was modelled as a yield-enhancing effect. Specifically, the total cost for a full non-GM farm is assumed to be cy , with the per-unit cost satisfying $c > 0$, whereas for a full GM farm the total cost is $(1 - \gamma)cy$, where $\gamma \in (0, 1)$ is the cost-saving coefficient.

As done by virtually all previous work on coexistence, we assume initially that coexistence regulations put the burden of implementing coexistence requirements on GM farms. The stated objective of these regulations is to prevent the externality effect they might have on non-GM farms. Specifically, we model this burden by requiring that a GM farm bordering a non-GM farm must establish a buffer zone. This portion of land is assumed to be planted with non-GM crop, but its output is to be marketed as GM product. Hence, the non-GM crop to be sold as such is effectively isolated from the GM crop by the buffer zone which, by assumption, is of sufficient size to prevent unintended contamination of the non-GM product (e.g. via pollen flow). This modelling approach represents in a straightforward fashion the ‘cost’ of coexistence measures: a GM farmer who must implement buffer zones obtains the GM cost saving only on a fraction of its land.

To give the model a spatial nature and retain analytical tractability, we think of farms as having dimension along a line, so that a GM farm can border a non-GM farm at either end, as illustrated in Figure 1. The size of the buffer zone required at the boundary between GM and non-GM areas is a fraction, $\beta > 0$, of the farm size. We assume $\beta < 1/2$, so that effective isolation of GM and non-GM production is, in principle, feasible by the action of a single farm. Furthermore, to avoid end-point asymmetries we assume that these farms are distributed along a circle.

As noted, the buffer zone is planted with the non-GM crop but its output is treated as GM output (because it is itself not isolated from the own-farm GM output). Thus, the cost saving of the new technology for a GM farm bordering a non-GM farm is reduced. If it borders a non-GM farm on one side only, as

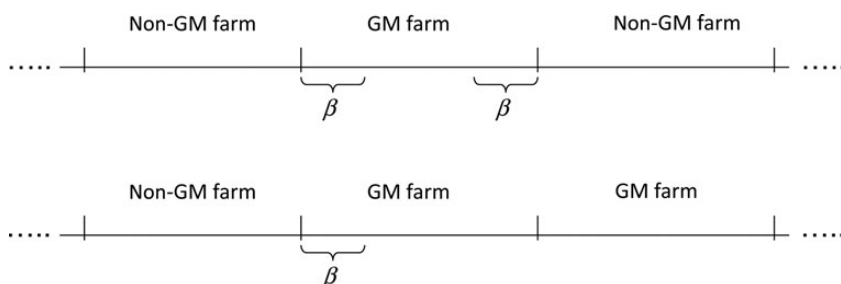


Fig. 1. Farms along a line and isolating buffer zones.

in the lower panel of Figure 1, the total cost of this GM farm is $(1 - \gamma)(1 - \beta)cy + \beta cy$. If the GM farm borders non-GM farms on both sides, as in the upper panel of Figure 1, its total cost is $(1 - \gamma)(1 - 2\beta)cy + 2\beta cy$. Therefore, for given output prices p_n and p_g of the non-GM and GM products, respectively, the profits of the possible types of farms are as follows

$$\pi_0^n = p_n y - cy, \tag{7}$$

$$\pi_0^g = p_g y - (1 - \gamma)cy, \tag{8}$$

$$\pi_1^g = p_g y - (1 - \beta)(1 - \gamma)cy - \beta cy, \tag{9}$$

$$\pi_2^g = p_g y - (1 - 2\beta)(1 - \gamma)cy - 2\beta cy, \tag{10}$$

where the superscript $i \in \{n, g\}$ denotes the type of farm (non-GM and GM, respectively), and the subscript $j \in \{0, 1, 2\}$ refers to the number of buffer zones that the particular farm is implementing.

3. Equilibria

A competitive equilibrium in our setting consists of a pair of equilibrium prices $p_n^* > 0$ and $p_g^* > 0$, and an allocation with $N_g^* \geq 0$ GM farms and $N_n^* \geq 0$ non-GM farms. These equilibrium values must satisfy three sets of conditions: (i) the markets for GM and non-GM products clear (no excess demand for either product); (ii) no farm has a unilateral incentive to change production type and (iii) farmers make non-negative profit. The supply side that we have outlined is constrained by land availability, such that $N_n^* + N_g^* \leq N$ must hold, and by strictly positive per-unit production costs. In equilibrium either of these two types of constraints could be binding. In what follows we intend to consider equilibria in which all land is used in production, both before and after the GM innovation. The required restriction on the parameter space can rely on the threshold parameter θ_0 introduced earlier, which identifies the consumer type who is indifferent between consuming one unit of the good or staying out of the market. When land is fully utilised, this parameter $\theta_0 \in (0, 1)$ satisfies

$$\theta_0 = \left(1 - \frac{N y}{M} \right). \tag{11}$$

Hence, the threshold parameter θ_0 represents the fraction of the potential market M that is not served at full production.³ To ensure that all the land is used in the pre-innovation equilibrium and in post-innovation equilibria, it suffices to require the following.

3 We note that this parameter can also be related to the (local) elasticity of total demand $X \equiv X_n + X_g$, where from Equations (2) and (3) it follows that $X = M(1 - p_g/q)$. When the (absolute value of the) demand elasticity $\varepsilon \equiv -(\partial X / \partial p_g)(p_g/X)$ is evaluated at the price configuration of full production (i.e. when $X = Ny$), it is then verified that $\theta_0 = \varepsilon / (1 + \varepsilon)$.

Assumption 1. *The parameters of the model satisfy $c \leq q\theta_0$.*

This assumption guarantees that all farmers make non-negative profit in all the equilibria that we analyse, and thus the equilibrium condition (iii) noted above will not be considered explicitly again in what follows.

In the post-innovation situation, depending on the parameters of the model, many types of equilibria are possible: coexistence equilibria in which both crops are grown, and specialised equilibria in which only one crop is grown (either the GM or the non-GM product). The critical determinants of equilibrium are: the size of the efficiency gain of GM production, parameterised by γ ; the size of consumers' additional willingness to pay for the non-GM product, *vis-à-vis* the GM product, parameterised by a and the cost of separating GM and non-GM production, parameterised by β . Because we are particularly interested in the conditions under which coexistence of both GM and non-GM farms attains in equilibrium, we analyse this case first. To steer clear of cumbersome analytics, throughout we treat the number N_g of GM farms and the number N_n of non-GM farms as real numbers, rather than integers (as long as the total number of farms N is reasonably large, there is little loss of generality with this approach).

3.1. Coexistence equilibria

For an equilibrium with coexistence of both GM and non-GM production, the allocation with $N_g^* > 0$ GM farms and $N_n^* > 0$ non-GM farms must clear the markets. Given Assumption 1, total output is predetermined: $X_n^* + X_g^* = N_n^*y + N_g^*y = Ny$. Hence, from Equations (4) and (11), the equilibrium price of the GM product is

$$p_g^* = q\theta_0. \quad (12)$$

The equilibrium price for the non-GM product, on the other hand, will depend on the amount of non-GM product grown in equilibrium. Specifically, from Equation (6) it will satisfy

$$p_n^* = p_g^* + a \left(1 - \frac{N_n^*y}{M} \right). \quad (13)$$

To pin down the equilibrium price for the non-GM product, we need to solve for N_n^* , which depends on cost parameters and on the spatial configuration of production that arises in equilibrium. Given the spatial equilibrium requirement that, at given prices, farms of different types (GM and non-GM) have no incentive to change the crop they grow, for all spatial equilibria with coexistence the following property applies.

Lemma 1. *In a coexistence spatial equilibrium, there can be no isolated GM farms.*

By ‘isolated GM farm’ we mean a farm that is bordered by non-GM farms on both sides, as illustrated in the top portion of Figure 1. Lemma 1 follows immediately by noting that, for such a configuration to be an equilibrium, one would need $\pi_2^g = \pi_0^n$ (at given prices). But this is not possible in equilibrium because the non-GM farm at this boundary would find it profitable to switch to GM production – this would result in the switching farm having, at most, only one buffer zone, and by assumption $\pi_1^g > \pi_2^g$.

Having ruled out coexistence equilibria with isolated GM farms, the relevant equilibrium condition is that, at the equilibrium prices, $\pi_1^g = \pi_0^n$. Using the definitions in Equations (7) and (9), this condition requires

$$\gamma c(1 - \beta) = p_n^* - p_g^*, \tag{14}$$

which, recalling Equation (12), implies

$$p_n^* = q\theta_0 + \gamma c(1 - \beta). \tag{15}$$

It is useful to note that p_g^* , which reflects the willingness to pay of the marginal consumer identified by θ_0 , is constant in this model (because of the assumption that all land is in production). However, this price does depend on the quality q of the GM product – as this quality attribute decreases, strictly positive GM production can be supported in equilibrium only by lower GM prices. The non-GM price p_n^* , on the other hand, is increasing in the efficiency gain parameter γ and decreasing in the coexistence burden parameter β . These properties reflect the supply-side competition brought about by the introduction of a more efficient production technique: the non-GM price reflects the willingness to pay of the marginal consumer $\hat{\theta}$ who is indifferent between the two goods, which increases as GM production displaces non-GM production.

The equilibrium price relation (Equation (14)) can be used to solve Equation (13) for the equilibrium number of non-GM farms

$$N_n^* = \left[1 - \frac{\gamma c}{a}(1 - \beta) \right] \frac{N}{(1 - \theta_0)}. \tag{16}$$

Given the constraint $N_g^* = N - N_n^*$, the equilibrium number of GM farms is then

$$N_g^* = \left[\frac{\gamma c}{a}(1 - \beta) - \theta_0 \right] \frac{N}{(1 - \theta_0)}. \tag{17}$$

As expected, the equilibrium number of non-GM farms is inversely related to improved efficiency of the GM crop (as captured by the cost-saving factor γc) and directly related to the parameter a that quantifies the intensity of preference of consumers for the non-GM product. In fact, the results of this article are best expressed in terms of the ratio of these two terms, $\gamma c/a$. It is also apparent that the equilibrium number of non-GM farms is directly related to parameter β indexing the costliness of the buffer zone requirements. Specifically, from Equations (16) and (17), it follows that to have a coexistence equilibrium with both $N_n^* > 0$

and $N_g^* > 0$ it is necessary that

$$\frac{\theta_0}{1 - \beta} < \frac{\gamma c}{a} < \frac{1}{(1 - \beta)}. \quad (18)$$

Although the foregoing characterises a competitive spatial equilibrium $(p_n^*, p_g^*, N_n^*, N_g^*)$, the fact remains that a number of spatial configurations of GM and non-GM farms might be consistent with this equilibrium. One such configuration, of course, is the most efficient spatial allocation that results in full agglomeration of GM and non-GM production (such that only two buffer strips are required, in total, to separate the set of farms that produce GM product from the set of farms that produce non-GM product). Even such an efficient equilibrium is not unique because the identity of the farms belonging to either set (GM or non-GM) is not determined. This has some relevance because, in the foregoing competitive equilibrium, firms belonging to the interior of the GM set make a strictly higher profit than all other firms. In any event, equilibria with partial agglomeration are also possible.

Figure 2 depicts two possible spatial equilibrium configurations with four GM farms and four non-GM farms. The situation on the left panel of this figure corresponds to full spatial agglomeration: the set of farms $\{1, 2, 7, 8\}$ produce the GM product and the set of farms $\{3, 4, 5, 6\}$ produce the non-GM product. The right panel of this figure illustrates an instance of partial agglomeration: the set of farms producing the GM product is $\{1, 2, 5, 6\}$ and the set of farms producing the non-GM product is $\{3, 4, 7, 8\}$. Note that because these two configurations entail exactly the same number of GM and non-GM farms, both equilibrium configurations are supported by the same equilibrium prices. Clearly the configuration in the right panel of Figure 2 is less efficient, as it entails higher buffer zone costs (the return to producers' fixed resource, land, is thus lowered).

3.2. Specialised equilibria

Coexistence between GM and non-GM products is clearly not the only possible competitive equilibrium outcome in this model, as specialised equilibria may

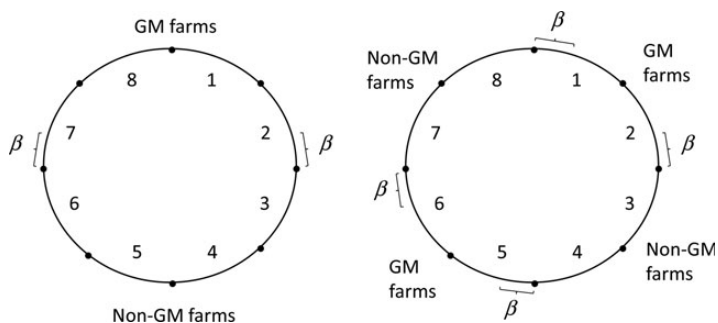


Fig. 2. Two possible spatial configurations of farms in competitive equilibrium.

also emerge. Consider first the possibility that only the GM good is produced in equilibrium, such that $X_g = Ny$ and $X_n = 0$. In this equilibrium the prices of the two products are $p_g^* = q\theta_0$ and $p_n^* = p_g^* + a$. For $N_g^* = N$ and $N_n^* = 0$ to be an equilibrium it must be that, at these prices, $\pi_0^n \leq \pi_0^g$, which requires $\gamma c/a \geq 1$. Hence, if the marginal willingness to pay for non-GM product of the highest valuation consumer is less than the cost saving that GM products yield (i.e. $a \leq \gamma c$), non-GM production is not attractive and all farms growing GM products constitute an equilibrium.

Comparing the parametric domain for the foregoing specialised equilibrium with the prior results concerning coexistence equilibria, we find that there is a range $\gamma c/a \in (1, 1/(1 - \beta))$, where a specialised equilibrium with only GM products and a coexistence equilibrium with both products are both possible. This is because, starting from a situation in which all farms are of the GM type, the condition required for any one farm to strictly prefer to switch to non-GM status is $\pi_0^n > \pi_0^g$. On the other hand, starting from a coexistence equilibrium, a competitive non-GM farm that borders a GM farm would find it strictly profitable to switch status only if $\pi_1^g > \pi_0^n$, and naturally $\pi_0^g > \pi_1^g$.⁴

Next, consider the case when only the non-GM good is produced. For $N_n^* = N$ to be an equilibrium, implying $X_g = 0$ and $X_n = Ny$, it must be that at the corresponding prices $p_g^* = q\theta_0$ and $p_n^* = (q + a)\theta_0$ it is not profitable for a single farm to switch to GM production, that is, $\pi_2^g \leq \pi_0^n$. From the profits in Equations (7) and (10), this requires $\gamma c/a \leq \theta_0/(1 - 2\beta)$.

Again, we have a parametric range in which both a coexistence equilibrium and a specialised equilibrium with only non-GM farms are possible. Specifically, this arises when $\gamma c/a \in (\theta_0/(1 - \beta), \theta_0/(1 - 2\beta))$. The reasons are similar to those given for the other specialised equilibrium. Starting from a specialised equilibrium with only non-GM farms, any one competitive farm will find it profitable to switch to GM status if $\pi_2^g > \pi_0^n$. On the other hand, from a coexistence equilibrium, a GM farm bordering a non-GM farm will find it strictly profitable to switch if $\pi_0^n > \pi_1^g$, and naturally $\pi_1^g > \pi_2^g$. The parametric domain $\gamma c/a \in (\theta_0/(1 - 2\beta), 1)$ defines what may be called the ‘robust coexistence’ set, where specialised equilibria are ruled out and only coexistence with both GM and non-GM products can arise in equilibrium. Quite clearly, the robust coexistence set can be empty, which arises when the buffer zone requirement is sufficiently large (i.e. when $\beta \geq (1 - \theta_0)/2$).

4. Welfare

To assess the efficiency of the competitive equilibrium, we need to compare it with the optimal allocation of land from the perspective of social welfare. Before proceeding to do that, however, it bears to note a particular feature of the model at hand which, while somewhat special to the parameterisation

4 A non-GM farm that does not border any GM farm would find it strictly profitable to switch status only if the stricter condition $\pi_2^g > \pi_0^n$ held.

chosen, nonetheless provides critical insights into the peculiar nature of GM technology innovation: the introduction of a weakly inferior good (Lapan and Moschini, 2004).

4.1. Consumer surplus decline

Because we are modelling the innovation as cost reducing, and total land is taken as given and fully utilised in both the pre-innovation and post-innovation equilibria, aggregate supply is perfectly inelastic. Given this feature, the standard VPD demand structure that we are using implies that, as long as we are in a coexistence equilibrium with $N_g^* > 0$ and $N_n^* > 0$, the innovation must increase the price of the non-GM product (relative to the pre-innovation equilibrium). This implication, and other results of this section, is best illustrated with the aid of Figure 3, which depicts both the pre-innovation equilibrium and the post-innovation coexistence equilibrium. Note that the assumption that land is fully used means that, using Equation (5) with $X_g = 0$ and $X_n = Ny$, the pre-innovation price of the non-GM product is $p_n^0 = (q + a)\theta_0$. In a coexistence equilibrium with $N_g^* > 0$ and $N_n^* > 0$, from Equation (15) the equilibrium price of the non-GM product is $p_n^* = q\theta_0 + \gamma c(1 - \beta)$. As long as $N_g^* > 0$, then from Equation (17) we find that $\gamma c(1 - \beta) > a\theta_0$, which implies $p_n^* > p_n^0$. Clearly, all consumers who still buy the non-GM product after the adoption of the GM product must be strictly worse off.

What about the consumers who elect to buy the GM product in the post-innovation situation? Recall that the consumers who buy the GM product

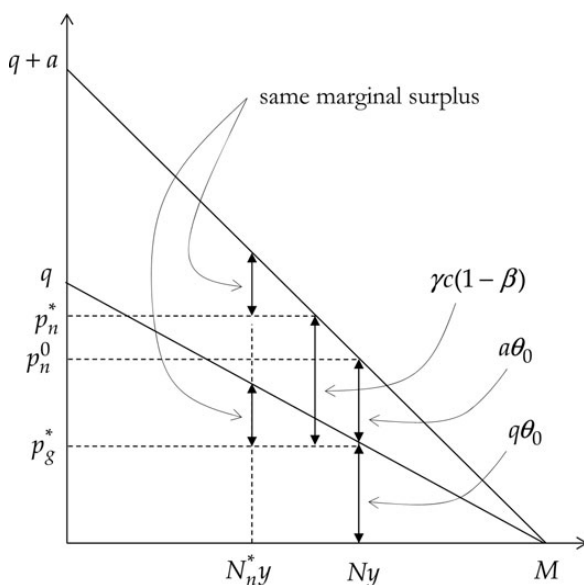


Fig. 3. Coexistence equilibrium.

have type $\theta \in [\theta_0, \hat{\theta}]$, where $\hat{\theta} \equiv (p_n - p_g)/a$ and $\theta_0 \equiv p_g/q$. Now consider the change in utility for a consumer of type θ who buys the GM product in the post-innovation situation. Her change in utility, relative to pre-innovation, is $\Delta U(\theta) \equiv \theta a - p_g^* - [\theta(a + q) - p_g^0]$, and thus $\Delta U(\theta) = -a(\theta - \theta_0) < 0$ for all $\theta > \theta_0$. Hence, even consumers who elect to buy the GM product in the post-innovation situation are strictly worse off as a result of the introduction of the GM product, except for the marginal consumer. This is summarised as follows.

Result 1. *With full utilisation of land in both the pre- and post-innovation equilibria, and given the assumed VPD preferences, adoption of the cost-reducing innovations makes all consumers strictly worse off (except for the marginal consumer who earns zero surplus in both situations).*

The reason for this result is that, because total land is given and the GM technology is modelled as cost-reducing (no yield effect), there is no change in aggregate production. Adoption of the cost-reducing innovation increases the returns to land, and the need for the non-GM product to compete for land with the newly introduced GM crop increases the full cost of production of the non-GM product. But of course, as detailed below, the innovation may still be valuable from a social point of view because of its efficiency (cost reducing) effect.

4.2. Pareto optimality

To derive the welfare maximising allocation of land, we first note that, for any given allocation, full agglomeration is optimal because it minimises the cost of separating GM and non-GM production. Conditional on full agglomeration, and given the demand and production structures assumed in the foregoing, the welfare function (total Marshallian surplus) associated with a given number $N_g \in [0, N]$ of GM farms can be written as

$$W = (q + a)(1 + \theta_0) \frac{Ny}{2} - Nyc - a \left(2\theta_0 + \frac{N_g y}{M} \right) \frac{N_g y}{2} + \gamma c N_g y - 2\beta y \gamma c, \quad (19)$$

where the first two terms on the RHS represent welfare prior to the innovation (total surplus when consumers only have the non-GM product, net of production costs), the third term is the loss in surplus from consuming the quantity $N_g y$ of GM product, the fourth term represents the total cost saving from GM production and the last term represents the cost of buffer zones.

Solving the first-order condition for an interior solution yields the welfare maximising solution for the number of GM farms

$$N_g^{**} = \frac{N}{(1 - \theta_0)} \left(\frac{\gamma c}{a} - \theta_0 \right), \quad (20)$$

where we have used Equation (11). Note that the cost of buffer zones is treated as

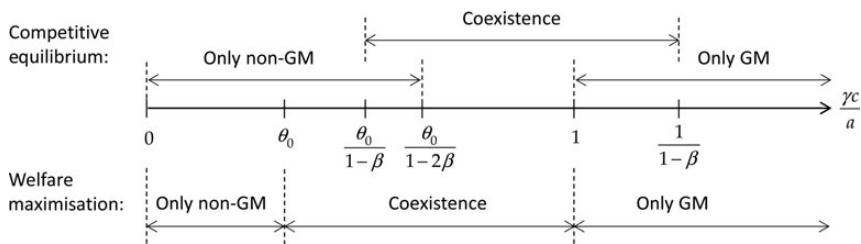


Fig. 4. Welfare maximisation and competitive equilibrium.

a fixed cost in the welfare maximisation problem and thus does not affect the optimal solution. For the solution in Equation (20) to satisfy $N_g^{**} \in [0, N]$, it is necessary that $\gamma c/a \in [\theta_0, 1]$. The lower bound indicates that cultivation of the GM product in a strictly positive amount is desirable only if $\gamma c > a\theta_0$, that is the per-unit cost saving is larger than the loss in marginal consumer surplus for the consumer with the lowest valuation of the good (at the pre-innovation equilibrium).⁵

The optimal number of non-GM farms can be obtained from the constraint $N_n^{**} \equiv N - N_g^{**}$. Recalling the structure of inverse demand functions, it follows that the welfare maximising solutions N_n^{**} and N_g^{**} correspond to prices p_n^{**} and p_g^{**} , which satisfy $p_n^{**} - p_g^{**} = \gamma c$. That is, welfare maximisation equates the marginal willingness to pay for the additional quality provided by the non-GM product, as given by the inverse demand functions, with the marginal cost of providing this quality upgrade, which is the foregone cost saving γc .

To sum up, the welfare maximising solution involves: only GM farms if $\gamma c/a \geq 1$; only non-GM farms if $\gamma c/a \leq \theta_0$ and coexistence with both GM and non-GM farms if $\gamma c/a \in (\theta_0, 1)$.

4.3. Inefficiency of the competitive coexistence equilibrium

The foregoing results highlight the fact that, when the cost of the buffer zone requirements are imposed on the GM farmers only, the competitive equilibrium is biased against the GM product. This is illustrated in Figure 4, where the parametric domains of various equilibria are defined relative to the ratio $\gamma c/a$.

Welfare maximisation requires that coexistence with some GM production takes place whenever $\gamma c/a > \theta_0$, but the competitive equilibrium can deliver some GM output only if $\gamma c/a > \theta_0/(1 - \beta)$, a higher threshold that is sensitive to the size of the mandated buffer zone parameter β . Indeed, as the analysis of the specialised equilibria illustrated, it is possible for an equilibrium with only non-GM farms to persist as long as $\gamma c/a \leq \theta_0/(1 - 2\beta)$, a higher threshold still. Similarly, the Pareto efficient solution calls for full conversion to GM

⁵ Strictly speaking, at the lower bound of the domain one should ensure that the welfare gain of coexistence at the optimal solution is sufficient to cover the fixed cost $2\beta\gamma c$ of coexistence. But clearly, for large enough N this fixed cost of coexistence can be ignored.

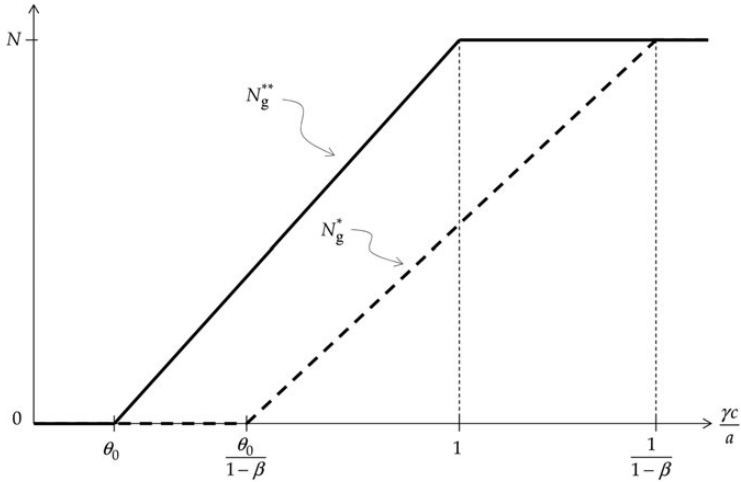


Fig. 5. Pareto optimality and the competitive equilibrium.

production whenever $\gamma c/a \geq 1$, but the competitive equilibrium can only achieve full GM specialisation when $\gamma c/a > 1/(1 - \beta)$.

To illustrate this point further, one can compare the welfare maximising solution N_g^{**} to the competitive market equilibrium N_g^* solution from Equation (17).⁶

Result 2. *In the domain where welfare maximisation requires coexistence (both products are produced), a policy that puts the burden only on GM producers leads to a competitive equilibrium which entails too little GM product (i.e. $N_g^* < N_g^{**}$).*

This results follows immediately because, by using Equations (17) and (20), the competitive equilibrium solution for the number of GM farms, in the relevant domain, can be written as

$$N_g^* = N_g^{**} - \frac{\beta\gamma cN}{(1 - \theta_0)a}.$$

The bias of the coexistence equilibrium is illustrated in Figure 5, where the solid line illustrates the Pareto efficient number of GM farms N_g^{**} , and the dashed line denotes the competitive equilibrium number of GM farms N_g^* , both expressed as a function of the relative efficiency ratio $\gamma c/a$.

6 Recall that the number of farms of this equation follow from the necessary conditions for coexistence, which, as the discussion of specialised equilibria indicates, may not be sufficient for coexistence to actually emerge.

To understand why coexistence policies that put the burden of segregation entirely on GM producers lead to a competitive equilibrium that does not achieve efficiency, it is important to appreciate the nature of the market failure at work. The premise of coexistence measures is predicated on the principle that GM producers exert an externality (e.g. pollen flow) on non-GM producers. Mandating buffer zones and/or isolation distances on GM producers forces GM farms that are adjacent to non-GM farms to internalise this external effect. In equilibrium, this leads to some agglomeration of like farms (recall Lemma 1), although the pattern of agglomeration that can arise in a competitive equilibrium is not unique. In such equilibria, however, GM producers who are at the boundary of the GM producing region exert a positive externality on GM producers who are located in the interior of this region (which permits them to avoid having to implement costly coexistence measures and thereby earn a profit $\pi_0^g > \pi_1^g = \pi_0^i$). These positive impacts are present in the welfare function and are captured by the welfare maximisation requirement of full agglomeration of like farms. But these positive impacts are not recognised by the coexistence measures that we have modelled and are not captured by the competitive equilibrium. This conclusion reflects a more fundamental property of the problem: whereas the cultivation of GM crops introduces an externality at the farm level, at the aggregate level it gives rise to a nonconvexity. As emphasised by [Lapan and Moschini \(2004\)](#), in a fully agglomerated equilibrium the external effects are not related to the quantity of a GM product that is produced, but to the fact the GM product is produced at all.⁷ This is apparent in the formulation of the welfare function in Equation (19) where the cost of coexistence essentially enters as a fixed cost.

4.4. Sharing coexistence measures

For a better appreciation of Result 2 it is important to note the inherent symmetry of the structure of the model and the asymmetry in the coexistence policy considered. If the burden of coexistence were reversed, such that the costs of buffer zones were to be borne entirely by non-GM producers, the opposite conclusion would attain: competitive equilibrium would yield too little non-GM production, relative to the welfare optimum.⁸ This observation motivates consideration of a policy that shares the cost of buffer zones between adjacent GM and non-GM farms. Specifically, suppose that non-GM farms bordering a GM farm are required to bear a share $\sigma \in [0, 1]$ of the buffer zone cost, while the bordering GM farms bears the remaining share $(1 - \sigma)$ of such costs. For

7 This feature is also present in [Munro \(2008\)](#), who considers a stylised model of GM and non-GM production. He does not relate the model to specific coexistence policies, assumes that the burden of isolation is entirely on non-GM producers and discusses mainly the special case in which non-GM production may fail to emerge in equilibrium.

8 In fact, if the burden of coexistence were entirely on non-GM producers, it would be possible for the GM crop to be adopted in equilibrium even when the efficiency parameter is low enough that zero adoption is optimal from a welfare perspective, similar to the result of [Moschini, Bulut and Cembalo \(2006\)](#).

either farm, the buffer zone is costly because it entails having to plant it as non-GM product (and thus without any cost savings) but having to sell the resulting output as GM product. Thus, for given output prices p_n and p_g , the profits of the possible types of farms are as follows:

$$\pi_1^n = p_n y(1 - \sigma\beta) + \sigma\beta p_g y - cy, \tag{21}$$

$$\pi_1^g = p_g y - (1 - (1 - \sigma)\beta)(1 - \gamma)cy - (1 - \sigma)\beta cy, \tag{22}$$

$$\pi_2^n = p_n y(1 - 2\sigma\beta) + 2\sigma\beta p_g y - cy, \tag{23}$$

$$\pi_2^g = p_g y - (1 - (1 - \sigma)2\beta)(1 - \gamma)cy - (1 - \sigma)2\beta cy, \tag{24}$$

where, as before, the superscript indicates the type of product (non-GM or GM) and the subscript refers to the number of neighbouring farms that produce the other products. The profit expressions for farms that do not implement any buffer strips (i.e. π_0^n and π_0^g) are of course the same as given in Equations (7) and (8).

As for the case where the burden of coexistence is fully on GM producers, considered earlier, we can rule out spatial configurations that require farms to implement buffer zones on both sides (i.e. isolated farms).

Lemma 2. *In a coexistence spatial equilibrium where coexistence measures are shared, there can be no isolated farms of any type (GM or non-GM).*

The reason for this property is that an isolated farm, of either type, could change the crop it grows and strictly increase its profit. Hence, in any equilibrium configuration farms will border at most one farm growing the other product. Equilibrium requires prices to be such that $\pi_1^n = \pi_1^g$ which, based on the foregoing, implies

$$(p_n^* - p_g^*)(1 - \sigma\beta) = (1 - (1 - \sigma)\beta)\gamma c. \tag{25}$$

Recall that, for welfare maximisation, the conditions for a coexistence equilibrium is that the marginal willingness to pay for the additional quality of the non-GM good be equal to the marginal cost of providing this quality upgrade (which is the foregone cost saving), that is $p_n^{**} - p_g^{**} = \gamma c$. From Equation (25), it is then immediately apparent that setting $\sigma = 1/2$ induces the competitive equilibrium with coexistence to achieve exactly the price conditions for welfare maximisation.⁹

Result 3. *Sharing the burden of the buffer zone requirement equally between neighbouring GM and non-GM farms leads to a coexistence equilibrium with*

9 Of course, the competitive equilibrium cannot guarantee the full spatial agglomeration that characterises the first best solution.

precisely the same number of GM and non-GM farms as entailed by the Pareto optimality conditions.

This result establishes that sharing the buffer zone requirement according to $\sigma = 1/2$ improves total welfare relative to $\sigma = 0$ (when the burden is entirely on GM producers). Some distributional implications, however, are perhaps worth noting at this juncture. The increase in welfare obtained by sharing coexistence measures, in this setting, is entirely due to production efficiency gains. As noted in Result 1, given the structure of the model, consumers are adversely affected by the introduction of the GM product. In fact, sharing coexistence measures leads to an expansion of the GM crop and reduction of the non-GM crop, and an increase in the price of the latter. Although total welfare is increased with $\sigma = 1/2$, relative to $\sigma = 0$, consumer surplus declines.

Note that in deriving Result 3 we have appealed to the Pareto efficient condition $p_n^{**} - p_g^{**} = \gamma c$ which, strictly speaking, was derived for the case where the buffer zone requirements are implemented on GM farms only. Sharing the buffer zone measures between GM and non-GM farms, rather than implementing such zones on GM farms only, is essentially equivalent from a welfare perspective because, in either case, the use of buffer zones requires non-GM crop to be grown and sold as GM product. A minor consideration is that, for any given number N_n and N_g of non-GM and GM farms, respectively, sharing the buffer measures means that a little less non-GM output (and a little more GM output) is available in the aggregate, compared with the case where the burden is entirely on GM farms. But it is of course still the case that full agglomeration of GM and non-GM production is desirable from a welfare perspective, so that only two buffer zones are required. Hence, when the total number of farms N is large, such differences in total aggregate output levels are inconsequential.

4.5. Specialised equilibria

To investigate the possibility of specialised equilibria when coexistence measures are shared, from the foregoing analysis we focus on the case $\sigma = 1/2$. Consider first the possibility that only the GM product is produced, that is $X_g = Ny$ and $X_n = 0$. For this to be an equilibrium it must be that, at the corresponding prices, $\pi_2^n \leq \pi_0^g$, which requires $(p_n^* - p_g^*)(1 - \beta) \leq \gamma c$. At this postulated equilibrium, the prices of the two products satisfy $p_n^* = p_g^* + a$, and so the parametric space that can support a specialised equilibrium with only GM production is $\gamma c/a \geq (1 - \beta)$. Next, suppose that only non-GM product is produced, that is $X_g = 0$ and $X_n = Ny$. For this to be an equilibrium it must be that, at the corresponding prices, $\pi_2^g \leq \pi_0^n$, which requires $\gamma c(1 - \beta) \leq (p_n^* - p_g^*)$. At this postulated equilibrium, equilibrium prices of the two products satisfy $p_n^* = p_g^* + a\theta_0$. Hence, the condition for only non-GM product to be supported in equilibrium is $\gamma c/a \leq \theta_0/(1 - \beta)$.

Similar to the case where buffer zones are mandated on GM farms only, therefore, in some domain of the parameter space we find that both coexistence and

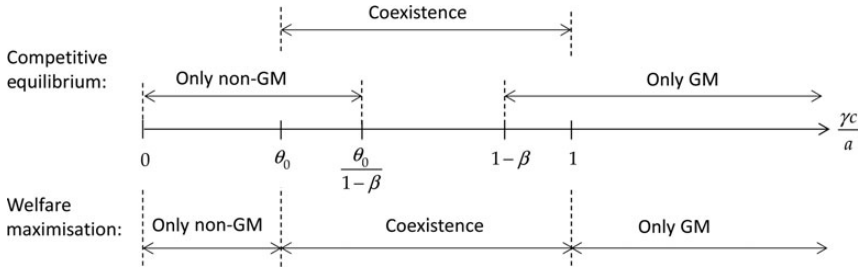


Fig. 6. Welfare maximisation and competitive equilibrium with $\sigma = 1/2$.

specialised equilibria may exist. Specifically, non-GM-only or coexistence may both be equilibria when $\theta_0 \leq \gamma c/a \leq \theta_0/(1 - \beta)$, and GM-only or coexistence may both be equilibria when $(1 - \beta) \leq \gamma c/a \leq 1$. This is illustrated in Figure 6.

5. Agreements between farmers and agglomeration

The inefficiency of the competitive equilibrium with coexistence could in principle be remedied, following Coase (1960), by negotiated agreements between farmers. If bargaining were costless, farmers could negotiate themselves to the efficient allocation regardless of who bears the burden of coexistence costs (Beckmann and Wessler, 2007). For example, farmers in the competitive equilibrium of the right panel of Figure 2 could negotiate production changes leading to the competitive equilibrium in the left panel of Figure 2. Both configurations entail the same aggregate supply of GM and non-GM products, and therefore the same equilibrium prices. However, the spatial configuration on the left panel of Figure 2 is more efficient because it entails lower total costs (fewer buffer zones). The presumption of costless bargaining, however, is difficult to maintain. Transaction costs are ubiquitous and significant in real economic environments, and arguably Coase’s analysis is best viewed as an invitation to explicitly account for these transaction costs (Tadelis and Williamson, 2013). Such costs are bound to be non-trivial for the case at hand because, as the characterisation of the problem in this article suggests, multilateral bargaining between large numbers of farmers in the agglomerated equilibrium may be required to achieve the first-best allocation.¹⁰ For example, moving from the configuration of the right panel of Figure 2 to that of the left panel of Figure 2 requires four of the eight farms (specifically, farms 5, 6, 7 and 8) to change type of production. Furthermore, such a change would strictly benefit only one of the four farms making the switch (farm 8, whose pay-off increases from π_0^n to π_0^s), indicating the need for side payments to bring about the change.¹¹

10 Ambec, Langinier and Marcoul (2012) consider coordination between producers in a more elaborate spatial setting (but, similar to most other coexistence studies, they eschew a full equilibrium analysis by assuming exogenously given prices for the two products).

11 Such a change would also strictly benefit one of the farms that remains a GM producer (farm 1), whose pay-off increases from π_1^g to π_0^g . This spillover effect suggests that to facilitate the

What about the prospect of limited bargaining possibilities between farmers? Suppose, for instance, that costless agreements between any two neighbouring farmers are possible (but agreements between three or more farmers are prohibitively costly). It turns out that this would have drastic implications for the competitive equilibrium.

Remark 1. *If costless agreements between any two neighbouring farmers are possible, only specialised equilibria can arise in a competitive equilibrium (or equilibrium may fail to exist).*

To see this, consider the coexistence equilibrium characterised in Section 3.1 where, at the equilibrium prices (p_n^*, p_g^*) , spatial equilibrium requires the condition $\pi_0^n = \pi_1^g < \pi_0^g$ to hold. By construction, no farm has a unilateral incentive to change production plan. But if the two neighbouring farms at the boundary of GM and non-GM regions could make an enforceable agreement, the non-GM farm could become a GM farm thereby raising their joint profit to $\pi_1^g + \pi_0^g > \pi_0^n + \pi_1^g$. This profitable opportunity is present for any pair of prices (p_n^*, p_g^*) for which $\pi_0^n = \pi_1^g$ holds, which means that such a coexistence equilibrium cannot exist. With respect to the possible cases illustrated in Section 3, this argument implies that the specialised non-GM-only equilibrium can attain if the parameters are such that $\gamma c/a \leq \theta_0/(1 - 2\beta)$, and the specialised GM-only equilibrium can attain if the parameters are such that $\gamma c/a \geq 1$. For the parametric domain $\gamma c/a \in (\theta_0/(1 - 2\beta), 1)$, on the other hand, no competitive equilibrium can exist if costless agreements between any two neighbouring farmers were possible.

Although the foregoing discussion provides a better appreciation for the nature of the model developed in this article, it does not detract from the main conclusions that we have drawn from the analysis. The fact remains that the presumption of costless bargaining is difficult to maintain. Assigning the burden of coexistence only to GM farmers penalises the adoption of the new technology in a clear way. If consumer preferences are such that preserving cultivation of the non-GM crop is valuable to society, the foregoing analysis shows that a more balanced approach that shares the burden of coexistence between GM and non-GM farmers might lead to an improved allocation of production.

6. Conclusion

The cultivation of GM crops makes it more costly to produce non-GM output because care must be taken to avoid unintended contamination of the latter. Whereas concerns about coexistence have emerged elsewhere as well, they

internalisation of the agglomeration benefits from any given suboptimal allocation, side payments may need to involve a larger set of farms than those changing production plans.

have taken central stage in the EU. Policies being considered and implemented emphasise the prevention of contamination at the farm level by such measures as isolation distances and buffer zones. This is justified by the observation that contamination is the result of an externality (e.g. pollen flow) that GM producers exert on non-GM producers. Implementing coexistence measures is costly, and policies being considered by EU member states appear to put this burden exclusively on GM producers.

By using an explicit spatial equilibrium model, in this article we have characterised some key consequences of such policies. By being forced to implement isolation measures such as buffer zones, a GM producer whose farm is adjacent to that of a non-GM producer internalises the externality that they exert on this non-GM producer. Equilibria with coexistence of both GM and non-GM products, however, inevitably display a degree of agglomeration (no isolated GM farm can exist in a competitive equilibrium). GM producers who are at the boundary of the GM and non-GM set of farms therefore exert a positive externality on GM producers in the interior who enjoy a higher profit because they do not need to implement buffer zones. Coexistence policies predicated on the polluter-pays principle, however, do not provide a mechanism for this positive externality to be compensated. The crux of the matter is that, from the point of view of welfare maximisation, the problem being addressed is not a standard externality, it is a nonconvexity: given that some GM product is desirable from the perspective of total Marshallian surplus, in the aggregate, buffer zones are a fixed cost to be paid for the need to isolate the production of the two products. As shown in this article, competitive equilibria that arise when the burden of coexistence is entirely on GM producers are biased against the adoption of GM crops.

Some caveats naturally apply to the analysis of this article. Although the hypothesis of VPD is attractive in our setting, and indeed it has been assumed (formally or informally) by a great many studies of the economic consequences of GM products, the parameterisation utilised (favoured in the literature for its analytical simplicity) is somewhat special. Similarly, we have modelled the efficiency-enhancing attribute of GM crops in terms of cost reduction rather than as yield increasing. Again, we have chosen our modelling strategy for its analytical clarity, but production theory can establish a duality between these two effects, suggesting that the results we obtain have some general validity. Limiting the model to only two products inevitably simplifies real-world agricultural landscapes, but it permits the analysis to focus crisply on some essential features of coexistence policies. The pay-off from the chosen modelling strategy is that it permits an explicit equilibrium analysis of coexistence measures, and such an equilibrium framework is an essential ingredient for welfare analysis.

In the simple competitive spatial equilibrium model of this article, we have also shown that the Pareto efficient allocation of land to GM and non-GM products could be supported by coexistence rules that share the burden of implementing isolating buffer zones between (adjacent) GM and non-GM farms. This result has immediate policy implications for the design of effective implementation of rules furthering the EU objective of ensuring coexistence between

GM and non-GM products. The emerging EU coexistence policies are highly controversial (Ramessar *et al.*, 2010). Similar to other post-market regulations, the fear is that they may be used instrumentally to keep GM products out of the market despite their having been cleared in the pre-market approval process. Taking the coexistence objectives at face value, we have shown that coexistence policies can be tailored to achieve efficient outcomes. For the specific model analysed in this article, this solution takes a particular simple form: the implementation of coexistence measures should be shared equally between contiguous GM and non-GM farms, evocative of Horace's dictum that '*in medio stat virtus*'. Although the fifty–fifty sharing rule, to a certain extent, reflects the particular parameterisation of the model, we believe that, more generally, our result suggests that a balanced approach to coexistence policies – one that does not unilaterally privilege pre-existing crop patterns but is instead open to efficiency-enhancing innovations – might be highly desirable.

Acknowledgements

I am grateful to Harvey Lapan for helpful discussions. I would also like to thank Marion Desquilbet, Justus Wesseler and the journal's anonymous reviewers for their comments. The usual disclaimer applies.

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