How do GM / non GM coexistence regulations affect markets and welfare?

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Abstract

This paper presents a theoretical economic model assessing the effect of the level of mandatory genetically modified (GM) / non-GM coexistence regulations on market and welfare outcome. We assume vertical differentiation of GM and non-GM goods on the consumer side. Producers are heterogeneous in their cost savings from GMO adoption. Producers of non-GM crops face a probability of having their harvest downgraded if gene flow from GM fields makes its GMO content above the labeling threshold. The government may impose to GMO producers mandatory *ex ante* isolation distances from non-GM fields in order to decrease the probability of non-GM harvest downgrading. It may also introduce an *ex post* compensation to non-GMO farmers for profit losses due to harvest downgrading, imposing GMO farmers' participation to a compensation fund via a tax on GM seeds. Assuming endogenous crop choices and prices, we study the effects of *ex ante* regulation and *ex post* liability of GMO producers on market equilibrium as well as on global and interest group welfare.

Keywords: genetically modified organisms, coexistence, identity preservation, regulation, liability, vertical differentiation, law and economics.

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1 Introduction

Ever since they have been commercialized, genetically modified organisms (GMOs) have been controversial. Many have supported them for their productivity gains and their possible future enhanced agronomic or nutritional characteristics. But many other people have opposed them on ethical grounds or because of potential health and environmental risks. How public authorities have regulated GMOs as a compromise between these two opposing groups has been influenced by the political shaping of the controversy. Public opinions and interest group involvement have been very different across countries and, as a consequence, current GMO regulations vary greatly across countries. Notably, in the US, GMO/non-GMO labelling is voluntary and coexistence between GMOs and non-GMOs is not regulated. On the opposite, in the European Union (EU), labelling of products containing GMOs is mandatory, unless this presence is adventitious and less than 0.9% per ingredient; in addition, traceability of GMOs is mandatory to facilitate their monitoring. More recently, European Commission (EC) recommendation 2003/556 has instituted a framework to regulate the coexistence of GM and non-GM crops in fields, a public policy that we analyze theoretically in this article.

The EC recommendation on coexistence institutes freedom of choice between GMOs and non-GMOs, for both producers and consumers, as a fundamental principle. It allows Member States to impose mandatory regulations on farmers growing GM crops in order to limit gene flows from their fields to neighboring non-GM fields. Currently adopted national regulations rely mainly on isolation distances, which define a minimum spacing between GM plantings and non-GM plantings dedicated to identity preserved (IP) non-GM markets. These isolation distances may be either planted with a non-GM variety of the same crop, or planted with another crop, or left uncultivated. In some countries, instead of isolation distances or as a complement to them, GMO farmers may choose to implement mandatory buffer zones, created by planting strips at the outer border of the GM field with a non-GM variety of the same crop, or staggered sowing. In addition, since civil law is generally in the responsibility of the Member States, these latter may also adopt specific provisions for liability in cases of GMO admixture and define procedures to compensate the economic damage of non-GM producers who end up facing GMO admixture above the tolerance threshold in their harvest. The EC recommendation defines this economic damage as the difference between the non-GM and GM product prices. Currently defined liability rules for farmers cultivating GMOs vary between states. In some countries these farmers must subscribe an insurance or a financial guarantee to feed a compensation fund, and are still liable even if they followed mandatory regulations set up to limit the extent of admixture. Other countries have not introduced specific liability rules and rely on general civil liability (Beckmann et al., 2006; Commission of the European Communities, 2003 and 2009).

From an economic perspective, the existence of GM crops makes production of non-GM crops more costly if farmers are to sell their crop as non-GM in order to meet the demand from consumers who view non-GM products as superior to GM products. In other words, the cultivation of GM crops creates a negative externality on non-GMO producers who intend to prevent GMO commingling above the labeling threshold in their harvest.

As an activity that creates risks of harm to others, cultivation of GMOs presents a specific difficulty: it is technically impossible to attribute the damage due to gene flows to a precise producer. In other words, the admixture related to gene flows is a case of non-point source pollution, since it cannot be traced back to a single or definite source. As a result, there is a chance that parties could not face the threat of suit for harm done. Therefore, tort liability alone is not an adequate regulation to solve the risk of GM gene flow towards non GM crops and *ex ante* safety regulation is warranted (Shavell, 1984). In addition, *ex post* tort liability is expected to be useful, since technical *ex ante* coexistence measures in fields do not entirely eliminate the risk of gene flow. These arguments call for coupling *ex ante* safety regulation with *ex post* liability regulation at the farm level.[1]

The necessity of a policy mix regulation is not specific to the issue of coexistence in fields. Indeed, in a wide number of areas dealing with externality-generating activities, regulation and liability are used jointly (Kolstad, Ulen and Johnson, 1990). Most forms of regulation combine *ex ante* and *ex post* components. More, Shavell (1984) suggests that *ex ante* safety regulation and tort liability can complement each other in that their joint use can optimally correct inefficiencies which appear when only one approach is used to correct an externality.

While a substantial agronomic literature addresses the effects of alternative *ex ante* regulations on GMO admixing (see e.g. Sanvido et al., 2008; Ceddia et al., 2009; Devos et al., 2008), there are yet few economic studies analyzing the impacts of coexistence regulations. Market and welfare models of GMO introduction in the presence of consumer aversion for GMOs usually assume that no coexistence regulation is in place (Lapan and Moschini, 2004; Fulton and Giannakas, 2004; Lapan and Moschini, 2007; Desquilbet and Bullock, 2009). Munro (2008) discusses policy

[1]In addition, GMO admixture may remain initially undetected and become known at latter stages of the food or feed production chain, which also makes it problematic to rely exclusively on *ex post* liability (Faure and Wibisana, 2008). We do not account for this potential problem in our framework in which only the farm production stage is modeled explicitly.

options to restore efficiency with a stylized market model of GM and non-GM crops in which GMO producers exert a spatial negative externality on non-GMO producers. He shows that market-based instruments such as a tax on GM seeds or a subsidy on non-GM production may be insufficient to ensure production efficiency. However, his discussion is not related to the current EU regulatory framework for coexistence.

The analysis of Demont et al. (2008 and 2009) is more in line with the current EU regulation. These authors discuss the effects of two alternative spatial *ex ante* coexistence regulations, namely, an isolation distance around non-GM fields (so that any farmer willing to grow a GM crop within this distance has to grow the non-GM variety of the same crop instead), and a pollen barrier (that is, a field border between a GM and a non-GM field), of a smaller length than the isolation distance, that has to be planted with a non-GM variety but harvested and marketed with the GM crop. The authors assume that this pollen barrier may be located either at the border of the GM field, or at the border of the non-GM field if the GMO farmer compensates the non-GMO farmer for the cost of this barrier. With this setting, the authors argue that small negotiable pollen barriers are preferable to large isolation distances, especially if market premiums for non-GM IP crops are inexistent or low. The generality of their result is however questionable, for two main reasons (Desquilbet and Bullock, 2010). First, these authors include only producers' profits, but not consumers' utility, in their analysis. Second, they adopt very restrictive assumptions, none of the non-GM crop production being downgraded with any of the two instruments, GM and non-GM prices being kept exogenous, and GMO adoption rates being kept exogenous as well.

In this paper, our aim is to contribute to this economic literature by analyzing the impact of *ex ante* and *ex post* coexistence regulations on prices and market shares of GM and non-GM products, global welfare and interest group welfare. We adopt a non-spatial stylized model where *ex ante* coexistence regulations are isolation distances on which GMO producers have to grow the non-GM crop. For simplicity reasons, we assume that GMO farmers comply perfectly with these technical measures (even though they bear additional costs because of this regulation). We also assume that non-GMO producers do not take any measure on their own to prevent GMO commingling. These producers face a probability of harvest downgrading that decreases with the *ex ante* regulation level (higher isolation distances diminish admixture risks) and that decreases with the regulatory tolerance threshold for GMO content in non-GM products. We assume that when *ex post* regulation is in place, GMO farmers have to contribute to a compensation fund via a tax on GM seeds, and that the government also participates to this compensation fund (via taxpayer money) in order to compensate exactly non-GMO farmers facing harvest downgrading for their profit loss. We model

GM and non-GM products as vertically differentiated on the consumer side. We use this model to analyze the effects of *ex ante* and *ex post* coexistence regulatory policies on market and welfare outcomes. A major characteristic of our model is to allow prices, GMO adoption rates and the extent of non-GM harvest downgrading to be endogenous.

2 Model

We assume that the government defines a regulatory threshold $s \in [0, 1]$ that denotes the proportion of authorized adventitious presence of GMOs in Identity Preserved (IP) non-GM products: if $s = 0$, no GMO presence at all is tolerated in the non-GM grain; while if $s = 1$, a 100% presence of GMOs is authorized in the non-GM grain, in other words the threshold is never binding. We assume that producers are profit-maximizers and may produce four goods: an alternative crop a, or three different types of a particular grain. The first one is produced using a GM seed and is indexed by g. The second type of grain (indexed by n) is produced from a non-GM seed but not sold as IP: either it is produced by non-GM producers but downgraded because its GMO content is above the regulatory threshold, or simply sold with GM crops in situations where non-GM producers have no economic advantage to sell it as IP; or it is produced by GMO producers on some part of their area to comply with an *ex ante* coexistence regulation, and mixed up with the GMO harvest. Consumers consider n and g to be the same product, that we call "regular" (indexed by r). The third type, indexed by i, is the IP grain: it is grown from a non-GM seed by non-GM producers, and conforms with labelling requirements (i.e. has a GMO content below the regulatory threshold). For simplicity reasons, we concentrate on the agricultural stage, which is the target of EU coexistence regulations, assuming that no additional commingling occurs at the handling and processing stages.

2.1 Consumers

As in Fulton and Giannakas (2004) and Lapan and Moschini (2007), we adopt a framework of vertical differentiation consistent with Mussa and Rosen (1978), in which the non-GM product is the high-quality product (all consumers appreciate equally the relative quality of GM and non-GM products but are heterogeneous in their willingness to pay for a given quality). We assume a continuum of consumers characterized by a willingness to pay for quality θ uniformly distributed between 0 and 1. Each consumer consumes either the GM good, or the non-GM good, or none, but never both. When consuming, a consumer consumes exactly one unit. The quality of the non-GM good with zero GMO content is normalized to 1. Consuming the regular product results in a discount in quality $\delta < 1$ (that is, the perceived quality of the GM good is $1-\delta$). When the regulatory threshold of authorized adventitious presence of GMOs in the non-GM good is s, we assume that the perceived quality of the non-GM good is $1-\delta s$ (the lower is the authorized presence of GMOs in the non-GM good and the higher is its perceived quality). Then, the utility of the consumer with a willingness to pay for quality θ is given by:

$$\begin{cases} \theta(1-\delta s) - p_i & \text{when he buys one unit of the IP good,} \\ \theta(1-\delta) - p_r & \text{when he buys one unit of the regular good, and} \\ 0 & \text{when he buys one unit of the alternative good,} \end{cases} \tag{1}$$

where p_i is the per-unit grain price of the IP good (the IP price) and p_r the per-unit grain price of the regular good (the regular price).

The following threshold values allow to characterize consumers' choices:[2]

$$\begin{cases} \theta^r &= \frac{p_r}{1-\delta}, \\ \theta^i &= \frac{p_i}{1-\delta s}, \\ \widetilde{\theta} &= \frac{p_i - p_r}{\delta(1-s)}. \end{cases} \tag{2}$$

All consumers characterized by $\theta > \theta^j$ ($j = r, i$) obtain a higher utility from consuming good j rather than the alternative good; while all consumers characterized by $\theta > \widetilde{\theta}$ obtain a higher utility from consuming the IP good rather than the regular good.[3] Immediate calculation shows that the threshold values of θ must verify either $\theta^r = \theta^i = \widetilde{\theta}$ (in which case any consumer is indifferent between consuming the IP good or the regular good), or $\theta^r < \theta^i < \widetilde{\theta}$, or $\widetilde{\theta} < \theta^i < \theta^r$. When $s < 1$,

[2]Formally, and omitting the argument δ, these thresholds are functions $\theta^r(p_r)$, $\theta^i(p_i, s)$, $\widetilde{\theta}(p_r, p_i, s)$. We drop their arguments to lighten the model writing.

[3]Our formulation is close to that adopted by Lapan and Moschini (2007). It is simpler, however, because we assume that consumers care for the regulatory threshold s, not for the actual GM content of the non-GM IP product - while in their paper the perceived quality of the non-GM good depends on the actual presence of GMOs in the non-GM good in equilibrium, which is at most equal to the regulatory threshold.

omitting the argument δ, our utility functions imply the following demand functions:

$$\text{For any } s \in [0,1),$$
$$D^r(p_r, p_i, s) = \begin{cases} \min(\widetilde{\theta}, 1) - \theta^r \text{ when } \theta^r < \theta^i, \\ 0 \text{ when } \theta^i \leq \theta^r. \end{cases} \tag{3}$$
$$D^i(p_r, p_i, s) = \begin{cases} 1 - \min(\widetilde{\theta}, 1) \;\text{ when } \theta^r < \theta^i, \\ 1 - \min(\theta^i, 1) \;\text{ when } \theta^i \leq \theta^r. \end{cases} \tag{4}$$

With a regulatory threshold $s = 1$ (i.e. when 100% of GMO content is authorized in the IP product), the IP label provides no information to consumers. Then, from our utility functions, there is a demand $D(p) = 1 - \min(\frac{p}{1-\delta}, 1)$ only for the cheapest product (or for any of the two products indifferently if their price is the same).

2.2 Producers

We assume the existence of a continuum of producers characterized by a parameter α, distributed uniformly on $[0, 1]$, that represents per-unit production costs for the GM crop. We assume that all producers face an overcost c_n when they produce the non-GM crop (which total per-unit production costs are therefore $\alpha + c_n$). We introduce the overcost of GM seed, w. Yield is identical for the two grain types n and g and is normalized at one unit per acre, making per-acre costs and per-unit costs the same. The profit obtained on the alternative crop is normalized to zero.[4] The IP farm price, p_i^-, equals the per-unit consumer price minus exogenous per-unit IP costs c_i at the handling and processing stages, $p_i^- = p_i - c_i$. We assume that the regular farm price equals its consumer price (there are no IP costs for the regular good).

In the absence of gene flow from GM to non-GM crops, per-unit profit functions take the form $\pi^g(p_r; \alpha) = p_r - \alpha - w$ and $\pi^n(p_i^-; \alpha) = p_i^- - \alpha - c_n$. We now define these profit functions in the presence of gene flow from GM to non-GM crops and when the government implements a regulatory threshold of maximum authorized GMO content in non-GM crops and a coexistence regulation.

[4]The heterogeneity in α together with the existence of the alternative crop allow to endogeneize the total supply of the GM and non-GM goods. We assume that all farmers have identical cost savings from GMOs for simplicity reasons: with heterogenous GMO cost savings, a range of equilibria exists in which all non-GMO producers are indifferent between preserving the identity of their good or selling it as regular together with the GM product without making IP efforts (Lapan and Moschini 2004, Desquilbet and Bullock 2009); while with homogenous GMO cost savings, all non-GMO producers are willing to IP their good in any equilibrium (see below).

2.2.1 Downgrading of non-GM production and policy parameters in the presence of gene flow

The government may implement an *ex ante* coexistence regulation that mandates each GMO producer to undertake a level of effort $e \in [0, 1)$, which represents a proportion of his land that he has to plant with the non-GM variety (which is then sold as regular together with the GM production). This formulation captures in a stylized fashion *ex ante* regulations such as isolation distances or pollen barriers, which impose GMO producers not to grow GMOs too close to non-GM fields.[5]

Non-GM producers sell their harvest as non-GM IP, at price p_i^-, if its GMO content is less that the regulatory maximum threshold s. However, if its GMO content is above this threshold, this production is downgraded, that is, sold as regular at price p_r. Noting the aggregate production of the GM good as Q_g, we model the probability of downgrading as a function $h(e, s, Q_g) \in [0, 1]$ which is decreasing in its two first arguments (the stricter the *ex ante* regulation, the lower the GMO content in non-GM harvest and therefore the proportion of downgrading; and the lower the authorized threshold of adventitious presence of GMOs, the higher the proportion of grain that does not meet this threshold) and increasing in its third argument. We assume that if the effort of GMO producers is maximum and/or if 100% GMO is authorized in the GMO product, all the non-GM production meets the standard ($h(1, s, Q_g) = h(e, 1, Q_g) = 0$). We define the probability of downgrading with the following functional form that verifies all these properties:

$$h(e, s, Q_g) = (1 - e)(1 - s)Ind(Q_g), \tag{5}$$

where $Ind(Q_g)$ is an indicator function equal to zero if no GMOs are produced and 1 otherwise ($Ind(Q_g) = 0$ if $Q_g = 0$ and 1 if $Q_g > 0$).

The government may also implement an *ex post* regulation by exactly compensating the profit losses faced by non-GMO producers if their production gets downgraded. We define this *ex post* regulation by an indicator function:

$$L = \begin{cases} 0 \text{ if no } \textit{ex post} \text{ regulation is in place,} \\ 1 \text{ if an } \textit{ex post} \text{ regulation is in place.} \end{cases}$$

[5]The actual constraint brought about by *ex ante* regulations in real landscapes is more complicated for two reasons: first, a GMO producer does not have to implement the *ex ante* regulation if he knows for sure at planting time that his neighbors are not willing to grow non-GM crops for identity preservation; second, the size and isolation of fields differ between producers, making the proportion of land affected by the *ex ante* regulation heterogenous between producers. For simplicity reasons these refinements are kept out of the scope of our model.

Each non-GM producer faces a probability $h(e, s, Q_g)$ that his crop gets downgraded. Given the continuum of producers facing the same probability, $h(e, s, Q_g)$ is also the proportion of total production by non-GM producers that gets downgraded. We assume that when an *ex post* regulation is in place ($L = 1$), the regulator uses two instruments to compensate profit losses of non-GM producers due to downgrading, a per-unit tax t on GM seed and a governement participation with taxpayer money.

2.2.2 Per-unit profit and aggregate supply functions

We denote by $\pi^g(.)$ the profit obtained by GMO producers who plant GMOs on a proportion $(1-e)$ of their area and the non-GM good on a proportion e of their area. Let $\pi^n(.)$ denote the expected profit of non-GMO producers. Given that the government implements the instruments s (regulatory threshold for GMO content in the non-GM grain), e (ex ante effort mandated on GMO producers) and L (ex post liability of GMO producers), omitting the argument c_n, the per-unit profit functions take the form:

$$\begin{aligned} \pi^g(p_r, e, L, t; \alpha) &= p_r - \alpha - (1-e)w - ec_n - (1-e)Lt, \\ \pi^n(p_r, p_i^-, Q_g, s, e, L; \alpha) &= p_i^- - \alpha - c_n - (1-L)(p_i^- - p_r)h(e, s, Q_g) \\ \pi^a &= 0 \end{aligned} \tag{6}$$

We define the threshold values α^i, $i = g, n$, so that all producers characterized by $\alpha < \alpha^i$ obtain a higher profit from producing good i rather than the alternative good ($\pi^i(.) > \pi^a \Leftrightarrow \alpha < \alpha^i$):

$$\begin{cases} \alpha^g &= p_r - (1-e)w - ec_n - (1-e)Lt, \\ \alpha^n &= p_i^- - c_n - (1-L)(p_i^- - p_r)h(e, s, Q_g). \end{cases} \tag{7}$$

From the profit functions defined above, it is immediate that when $\alpha^n > \alpha^g$ all producers obtain a higher profit from producing the non-GM good (n) rather than the GM good with the non-GM good on some part of the area (g); inversely, when $\alpha^n < \alpha^g$, all producers obtain a higher profit from n than from g; while when $\alpha^n = \alpha^g$, all producers obtain the same profit from n and g.

Let $\mathtt{P}_g$ and $\mathtt{P}_n$ denote the domains where the profit-maximizing choice of producers is to produce, respectively, the GM good combined with the non-GM good on the proportion of area e, and the non-GM good. Using the above properties, our profit functions imply the following profit domains:

$$
\begin{array}{ll}
\text{when } \alpha^n > \alpha^g, & \begin{cases} \mathtt{P}_g = \emptyset \\ \mathtt{P}_n = \{\alpha \in [0,1] : \alpha \leq \alpha^n\} \end{cases} \\
\text{when } \alpha^n = \alpha^g, & \mathtt{P}_g \cup \mathtt{P}_n = \{\alpha \in [0,1] : \alpha \leq \alpha^g\} \\
\text{when } \alpha^n < \alpha^g, & \begin{cases} \mathtt{P}_g = \{\alpha \in [0,1] : \alpha \leq \alpha^g\} \\ \mathtt{P}_n = \emptyset \end{cases}
\end{array}
$$

Let Q_g^s, Q_n^s and Q_i^s denote quantities supplied of goods g, n and i. On the domain $\mathtt{P}_g$, a proportion e of production is non-GM, because of the obligation for GMO producers to implement isolation distances sown with non-GM seeds. The remainder, that is, a proportion $1-e$ of production, is GM. On the domain $\mathtt{P}_n$, a proportion $1-h(.)$ is sold as IP while a proportion $h(.)$ gets downgraded because of excessive GM commingling. Our profit functions therefore imply the following supply correspondence:

For any $e \in [0,1)$,

$$
\begin{aligned}
&S(p_r, p_i^-, Q_g, s, e, L, t) = \big(S^g(p_r, p_i^-, Q_g, s, e, L, t), S^n(p_r, p_i^-, Q_g, s, e, L, t), S^i(p_r, p_i^-, Q_g, s, e, L, t)\big) \\
&= \Bigg\{(Q_g^s, Q_n^s, Q_i^s) : Q_g^s = (1-e)\int_{\alpha \in \mathtt{P}_g} d\alpha,\ Q_n^s = e\int_{\alpha \in \mathtt{P}_g} d\alpha + h(e,s,Q_g)\int_{\alpha \in \mathtt{P}_n} d\alpha, \\
&Q_i^s = (1-h(e,s,Q_g))\int_{\alpha \in \mathtt{P}_n} d\alpha\Bigg\}
\end{aligned}
\tag{8}
$$

2.3 Equilibria

Given the model's parameters δ, c_n, c_i, w and the policy instruments s, e, L, t, we have that p_r, p_i^-, p_i, $Q_g \in R_+^4$ is an *equilibrium* if: (a) $Q_g^s = Q_g$, (b) $p_i = p_i^- + c_i$, (c) $(Q_g^s, Q_n^s, Q_i^s) \in S(p_r, p_i^-, Q_g, e, s, L, t)$ (i.e. each producer maximizes profits); (d) $Q_g^s + Q_n^s = D^r(p_r, p_i, s)$ and $Q_i^s = D^i(p_r, p_i, s)$ (each consumer maximizes utility and markets clear).

3 The effects of *ex ante* versus *ex post* coexistence regulation

We now study several forms of regulation: no regulation, a regulatory maximum threshold for the adventitious presence of GMOs in the non-GMO production, *ex ante* regulation in addition, and *ex ante* regulation with *ex post* liability.

3.1 Benchmark cases: equilibrium without GMOs; equilibrium with GMOs and no regulation

In a benchmark situation in which GMOs have not been introduced (and therefore in which non-GMO producers bear no costs of IP and non-GMO consumers perceive no discount of quality), the non-GM good provides a per-unit profit $p - \alpha - c_n$, and a per-unit utility $\theta - p$. The equilibrium condition is $p - c_n = 1 - p$ and the equilibrium price is $p^0 = \frac{1+c_n}{2}$.

Consider now the situation where GMOs are introduced without any regulation, that is, no label (or equivalently $s = 1$ in our model) and no coexistence regulation ($e = L = t = 0$). The GM and non-GM goods provide per-unit profits $\pi^g = p_r - \alpha - w$ and $\pi^n = p_i - c_n - \alpha$ ($c_i = 0$ since there is no segregation costs), respectively, while consumers demand only the cheapest product, with $D(p) = 1 - \frac{p}{1-\delta}$. In this situation, the IP good would be produced only if it were cheaper to produce than the regular good. In equilibrium, only the IP good is produced and consumed if $w \geq c_n$ and the equilibrium price is equal to $\frac{1-\delta}{2-\delta}(1+c_n)$. If $w < c_n$, only the GM good is produced and consumed and the equilibrium price is then $\frac{1-\delta}{2-\delta}(1+w)$.

3.2 Equilibrium with labeling and *ex ante* coexistence regulation

Proposition 1 below summarizes all possible equilibria with labeling ($s < 1$) and ex ante regulation ($e \geq 0$) when no *ex post* regulation is in place ($L = 0$).

Proposition 1. *Assume that $s < 1$, $e \geq 0$ and $L = 0$.*

A. In any equilibrium in which the GM and the IP good coexist, prices are given by $p_r = \frac{1-\delta}{2-\delta}(1 + (1-e)w + ec_n)$ *and* $p_i = \frac{1-\delta}{2-\delta}(1 + (1-e)w + ec_n) + \frac{(1-e)(c_n-w)}{1-(1-e)(1-s)} + c_i$.

Producers characterized by $0 \leq \alpha \leq \alpha^g$ (with $\alpha^g = \alpha^n$) produce either the GM good with the mandatory isolation distance, or the non-GM good with some downgrading (all of them are indifferent between these two production choices). Consumers characterized by $\theta^r \leq \theta \leq \widetilde{\theta}$ consume the regular good, while consumers characterized by $\widetilde{\theta} < \theta \leq 1$ consume the IP good. Such a coexistence equilibrium arises if and only if:

$$\delta(1-s) \geq \frac{(1-e)(c_n - w)}{1-(1-e)(1-s)} + c_i \qquad (\text{C}1_0^-)$$

$$\delta(1-s) < \frac{2-\delta}{1+(1-e)w+ec_n}\left[\frac{(1-e)(c_n-w)}{1-(1-e)(1-s)} + c_i\right] \qquad (\text{C}2_0)$$

B. In any equilibrium in which only the GM good is produced, the regular price is also

$p_r = \frac{1-\delta}{2-\delta}(1 + (1-e)w + ec_n)$. *Producers characterized by* $0 \leq \alpha \leq \alpha^g$ *all produce the GM good (sowing the non-GM seed on a proportion* e *of their area), while consumers characterized by* $\theta^r \leq \theta \leq 1$ *consume the regular good. Such an equilibrium arises if and only if:*

$$\delta(1-s) < \frac{(1-e)(c_n - w)}{1-(1-e)(1-s)} + c_i \qquad (C1_0^+)$$

$$(1-e)w + ec_n < 1 - \delta \qquad (C3_0)$$

C. In any equilibrium in which only the IP good is produced, the IP equilibrium price is $p_i = \frac{1-\delta s}{2-\delta s}(1 + c_n + c_i)$. *Producers characterized by* $0 \leq \alpha \leq \alpha^n$ *all produce the IP good, which is consumed by consumers characterized by* $\theta^i \leq \theta \leq 1$. *Such an equilibrium arises if and only if:*

$$[(1-e)(2-\delta s) - \delta(1-s)]c_n - (1-e)(2-\delta s)w + c_i(2-\delta) \leq \delta(1-s), \qquad (C4_0)$$

$$c_n + c_i < 1 - \delta s. \qquad (C5)$$

Proof. See Appendix A.1. □

We note from Proposition 1 that the equilibrium domains with GM production only and with coexistence have a common frontier, with the opposite conditions $(C1_0^+)$ and $(C1_0^-)$, while there is no common frontier between the equilibrium domains with coexistence and with IP production only. Thus, for some value of the parameters, there are multiple equilibria with coexistence equilibrium. Figures 1 and 2 illustrate the results of Proposition 1 in the (w, c_n) plan (see Appendix A.4). The figure 1 (2) represents equilibria when IP costs (c_i) are relatively low (high). Lines $Ck0$ with $k = 1, ..., 5$ represent equalities of conditions (Ck_0) (see Appendix A.3). When c_i is relatively low, the area where the IP grain is cultivated and sold is larger than the one when c_i is high. And the multiple equilibrium in this first case corresponds to coexistence (i, r) and IP cultivation (i). When c_i is high, it corresponds to coexistence (i, r) and GMO cultivation (r).

Multiple equilibrium case results from the existence of the indicator function in the definition of the non-GM downgrading: some part of the IP production is downgraded if and only if the GM production is positive, which introduces a discontinuity between the equilibria with and without GMOs produced. [6]

[6] To avoid having some parameter values for which no equilibrium is defined, we could assume the possible existence of some equilibria in which the GM good is not profitable, yet is produced in an infinitesimal amount, together with some IP good, making the non-GM downgrading positive. Further analysis would be necessary to check that the domain of such an equilibrium would have common frontiers with both the coexistence and the IP equilibrium domains.

It is interesting to study how conditions (Ck_0) change when the level of *ex ante* regulation e increases. We obtain the following corollary.

Corollary 1.

- *When $c_i > \frac{(1-s)\delta(1+w)}{2-\delta}$, an increase in the level of ex ante regulation may cause the emergence of an equilibrium with coexistence, from a situation where only the GM good (combined with non-GM production on a proportion of area e) was produced and consumed in equilibrium.*

- *When $c_i < \min\{\frac{(1-s)\delta(1+w)}{2-\delta},\ (1-s)\delta\}$, an increase in the level of ex ante regulation may cause the emergence of an equilibrium with coexistence, from a situation where only the IP good was produced and consumed in equilibrium.*

- *For some values of the same parameters ($c_i > \max\{\frac{(1-s)\delta(1+w)}{2-\delta},\ (1-s)\delta\}$ and $c_i < \frac{(1-s)\delta(1+w)}{2-\delta}$), an increase in e may cause an equilibrium in which GMOs and IP coexisted to disappear in favor of only one of these productions (GMOs or IP).*

It is interesting to discuss the implication of this corollary in the light of the recent economic literature on coexistence regulation. As indicated by the first part of this corollary, the absence of IP goods on the market when coexistence is not regulated does not necessarily indicate that consumers are not interested in them. It may simply indicate that gene flow in fields, and the implied downgrading of IP production, makes such production too expensive in the absence of regulation. But this production choice may become profitable when coexistence measures imposed on GMO producers reduce the probability of gene flow towards non-GM fields. This endogeneity of production choices therefore makes the analysis more complicated than what is suggested for example by Devos et al. (2008) when they state that

"In markets where consumers are unwilling to pay significant price premiums for GM-free maize, there is no coexistence issue stricto sensu. Under market conditions where hardly any GM-free gains can be captured, wide and fixed isolation distances may generate substantial opportunity costs for maize producers who forego GM gains due to proximity to non-GM maize fields, and who are hardly capturing any compensatory GM-free gains. Moreover, this loss is not proportional to the weak incentives to supply non-GM crops and to ensure coexistence with non-GM crops."

Because producers' incentives to supply GM or non-GM crops are endogenous and subject to change when regulation is introduced, the absence of market signals for IP crops in the absence of coexistence regulation is not an indicator that such coexistence policy is not desirable.

In an equilibrium with coexistence, the utility of a consumer of the regular good is $\theta(1-\delta)-p_r$, the utility of a consumer of the IP good is $\theta(1-\delta s)-p_i$, and the profit of a producer of the GM or non-GM good is $p_r - ec_n - (1-e)w - \alpha$. From Proposition 1, we have the following corollary.

Corollary 2. *When the price of the GM seed is lower than the non-GM crop over-cost ($w < c_n$), in an equilibrium in which GMOs coexist with the IP good, an increase in the level of ex ante regulation causes the regular price to increase and the IP price to decrease, which favors consumers of the IP good, and hurts consumers of the regular good as well as producers.*

It also causes a decrease in the aggregate (regular + IP) production, as the resultant of a lower regular production level and a higher IP production level.

Considering a situation where GMOs are the less costly technology without any regulation, at initial market prices, the first effect of the *ex ante* coexistence regulation is to force GMO farmers to dedicate some of their area to isolation distances sown with non-GM seeds, decreasing their profitability while leaving their total production of regular good unchanged (since GM and non-GM goods have identical yields in our setting). The aggregate production of IP producers is unchanged too, but the proportion of their production that gets downgraded because of excessive GMO commingling decreases. Therefore, as a first effect, at initial market prices, the profitability of the GM crop decreases while the profitability of the IP crop increases. Also, the regular production decreases and the IP production increases (with the total production being unchanged), which tends to make the regular price increase and the IP price decrease. These second-effect price changes then increase the profitability of the regular crop and decrease the profitability of the IP crop (these two profitabilities have to become equal again for a coexistence equilibrium to be sustained after the regulation introduction).

The aggregate welfare level, which is the sum of producers' profits, utility of consumers of the regular good, and utility of consumers of the IP good, is given by:

$$W_0 = \int_0^{\alpha^g} (p_r - ec_n - (1-e)w - \alpha)d\alpha + \int_{\theta^r}^{\widetilde{\theta}} (\theta(1-\delta) - p_r)d\theta + \int_{\widetilde{\theta}}^{1} (\theta(1-\delta s) - p_i)d\theta.$$

Deriving this welfare level with respect to e when $e = 0$, we obtain the following proposition.

Proposition 2. *When the price of the GM seed is lower than the non-GM crop over-cost ($w < c_n$), in an equilibrium with coexistence of GMOs and IP, the introduction of ex ante regulation is welfare-increasing if and only if the following condition holds:*

$$\frac{\partial W_0}{\partial e}\ |_{e=0} > 0 \Leftrightarrow \frac{c_n(1-s^2)-w}{s^2} + \frac{c_n(1+w)}{2-\delta} - \frac{(c_n-w)(c_n-w+c_i s)}{(1-s)s^3\delta} > 0$$

This condition is more likely to hold if the aversion towards GMOs, δ, and the GM seed cost, w, are large, and the overcost of non-GM production and the IP cost, c_n and c_i, are small (while there is no general property on the level of the regulatory threshold, s, under which this condition is more likely to hold).

The possible welfare-increasing effect of the *ex ante* regulation arises because this regulation makes it possible to internalize on GMO producers some of the externality that they exert towards IP producers through gene flow, which production is preferred by consumers.

3.3 Equilibrium with labeling, *ex ante* and *ex post* coexistence regulation

Proposition 3 below summarizes all possible equilibria with labeling ($s < 1$) and *ex ante* as well as *ex post* coexistence regulation ($e \geq 0$, $L = 1$, $t \geq 0$).

Proposition 3. *Assume that $s < 1$, $e \geq 0$, $L = 1$ and $t \geq 0$.*

A. In any equilibrium in which the GM and the IP good coexist, prices are given by $p_r = \frac{1-\delta}{2-\delta}(1 + ec_n + (1-e)(w+t))$ and $p_i = \frac{1-\delta-ec_n-(1-e)(w+t)}{2-\delta} + c_n + c_i$.
Such a coexistence equilibrium arises if and only if:

$$\delta(1-s) \geq (1-e)(c_n - w - t) + c_i \tag{C1_1^-}$$

$$\delta(1-s) < \frac{2-\delta}{1+(1-e)(w+t)+ec_n}\left[(1-e)(c_n - w - t) + c_i\right] \tag{C4_1^+}$$

B. In any equilibrium in which only the GM good is produced, the regular price is $p_r = \frac{1-\delta}{2-\delta}(1 + ec_n + (1-e)(w+t))$, as in the coexistence case. Such an equilibrium arises if and only if:

$$\delta(1-s) < (1-e)(c_n - w - t) + c_i \tag{C1_1^+}$$

$$(1-e)(w+t) + ec_n < 1 - \delta \tag{C3_1}$$

C. In any equilibrium in which only the IP good is produced, the IP equilibrium price is $p_i = \frac{1-\delta s}{2-\delta s}(1 + c_n + c_i)$. Such an equilibrium arises if and only if:

$$\frac{2-\delta}{1+(1-e)(w+t)+ec_n}\left[(1-e)(c_n - w - t) + c_i\right] \leq \delta(1-s) \tag{C4_1^-}$$

$$c_i + c_n < 1 - \delta s \tag{C5}$$

In any of these equilibria, production and consumption choices depending on the values of parameters α and θ are defined as in Proposition 1.

Proof. See Appendix A.2. □

In this case, there is no multiple equilibrium because IP producers are fully compensated in case of downgrading; the indicator function does not appear here. Figure 3 illustrates the results of Proposition 3 in the (w, c_n) plan (see Appendix A.4). Coexistence equilibrium (i, r) appears when the costs related to the production and distribution of the IP good (c_n and c_i) are relatively similar to the costs related to the production and the regulation of the GM grain ($(1-e)w$ and $(1-e)t$).

In our model, *ex post* regulation consists in fully compensating IP producers for their profit losses if they have to downgrade some part of their production due to excessive GMO commingling, and is funded by taxpayer money and/or a tax on GM seeds. When such regulation is funded by taxpayer money alone, that is, when the GM seed tax t is set to zero, it is immediate that condition $\mathrm{C1}_1^-$ is looser than its counterpart in the absence of *ex post* regulation (that is, $\mathrm{C1}_0^-$), while conditions $\mathrm{C1}_1^+$ and $\mathrm{C4}_1$ are stricter that their counterparts ($\mathrm{C1}_0^+$ and $\mathrm{C2}_0$). Moreover, the introduction of a participation of GMO producers in the way of a GM seed tax (that is, the introduction of a positive t) makes condition $\mathrm{C1}_1^-$ even looser and conditions $\mathrm{C1}_1^+$ and $\mathrm{C2}_1$ even stricter. This implies the following corollary.

Corollary 3. *For a given level of ex ante regulation, the introduction of ex post regulation, funded by taxpayers and/or by a tax on GM seeds, may cause the emergence of an equilibrium with coexistence, or may cause an equilibrium in which GMOs and IP coexisted to disappear, in a similar way to the effects of the introduction of ex ante regulation described above.*

In an equilibrium with coexistence, the utility of a consumer of the regular good is $\theta(1-\delta)-p_r$, the utility of a consumer of the IP good is $\theta(1-\delta s)-p_i$, and the profit of a producer of the GM or non-GM good is $p_r - ec_n - \alpha - (1-e)t - (1-e)w$.

Corollary 4. *In an equilibrium with coexistence of GMOs and IP, for a given level of ex ante regulation, the introduction of ex post regulation funded by taxpayer money only leaves the regular price unchanged while it causes the IP price to decrease. It causes an increase in the utility of IP consumers and a cost to taxpayers, while it affects neither producers' profits, nor the utility of regular consumers. The total production level is kept unchanged, with the IP quantity higher and the regular quantity lower. The non-GM production that gets downgraded is proportional to the total IP production and therefore increases as well.*

Given that such ex post regulation is in place, and keeping the level of ex ante regulation unchanged, the introduction of a GM seed tax as as substitute to taxpayer funding of downgrading *compensation induces an increase in the regular price and a decrease in the IP price. It causes an increase in IP consumers' utility, and a decrease in producers' profits and regular consumers' utility. The total production level decreases, with the IP quantity higher and the regular quantity lower. The non-GM production that gets downgraded increases again.*

The aggregate welfare level is the sum of producers' profits and utility of both types of consumers, minus the damage funded by taxpayer money. The total compensation to IP producers for the downgrading they incur is $\frac{h}{1-h}(1-\widetilde{\theta})(p_i - c_i - p_r)$, of which $(\widetilde{\theta} - \theta_r - \frac{h}{1-h}(1-\widetilde{\theta}))(1-e)t$ is paid by the GM seed tax revenue and the rest by taxpayers.[7] Therefore this welfare level is given by:

$$W_1 = \int_0^{\alpha^g} (p_r - ec_n - \alpha)d\alpha + \int_{\theta^r}^{\widetilde{\theta}} (\theta(1-\delta) - p_r)d\theta + \int_{\widetilde{\theta}}^{1} (\theta(1-\delta s) - p_i)d\theta$$
$$-\frac{h}{1-h}(1-\widetilde{\theta})(p_i - c_i - p_r) + (\widetilde{\theta} - \theta_r - \frac{h}{1-h}(1-\widetilde{\theta}))(1-e)t.$$

The effect of the introduction of *ex post* regulation funded by taxpayers only is obtained by comparing $W_1 \mid_{t=0}$ with W_0 that was defined in the section above, that is, the welfare level with *ex ante* regulation only. Then, the effect of the GM seed tax is obtained by examining the sign of the derivative of W_1 with respect to the tax level t. Both effects are welfare decreasing, as summarized in Proposition 4 below.

Proposition 4. *In an equilibrium with coexistence of GMOs and IP, for a given level of ex ante regulation, the introduction of ex post regulation funded by taxpayer money only is necessarily welfare-decreasing. Given that such taxpayer-funded ex post regulation is in place, aggregate welfare decreases even further if a GM seed tax of any level is implemented in order to contribute to the funding of compensations for non-GM crop downgrading.*

This proposition indicates that the implementation of taxpayer-funded *ex post* regulation increases the utility of IP consumers only at the cost of a higher expense for taxpayers and is therefore never a warranted policy option. Introducing a GM tax creates a distortion that makes the welfare decrease even worse. This result is not surprising given that the *ex post* regulation, whether it is

[7] The equilibrium IP quantity consumed is $1-\widetilde{\theta}$, which implies that the total production of IP producers is $\frac{1-\widetilde{\theta}}{1-h}$ (of which a proportion $h = (1-s)(1-e)$ gets downgraded and a proportion $1-h$ is sold as IP). The equilibrium regular quantity consumed is $\widetilde{\theta} - \theta_r$, of which $\frac{h}{1-h}(1-\widetilde{\theta})$ is downgraded production of IP producers. Therefore the equilibrium quantity produced by regular producers is $\widetilde{\theta} - \theta_r - \frac{h}{1-h}(1-\widetilde{\theta})$, of which a proportion (1-e) is sown with GM seeds. As a result, the revenue from the GM seed tax is $(\widetilde{\theta} - \theta_r - \frac{h}{1-h}(1-\widetilde{\theta}))(1-e)t$ and the total compensation for downgraded IP production is $\frac{h}{1-h}(1-\widetilde{\theta})(p_i^- - p_r)$.

funded by taxpayers or GMO producers, gives no incentive to GMO producers to decrease the amount of damage suffered by IP producers. This effect is a direct consequence of our assumption that GMO producers never undertake any effort to decrease gene flow in the absence of a restrictive *ex ante* policy. It is in accordance with the non-point source nature of GM gene flow, which makes it possible for any individual producer to escape the threat of being held individually liable for its actions, therefore giving him no incentive to internalize the externality that he exerts on producers wishing to identity-preserve their non-GM crop.

3.4 Conclusion

In this paper we have examined the effects of *ex ante versus ex post* regulation of GM / non-GM coexistence in fields. To this aim, we have defined a framework that allows to make prices, and therefore production and consumption choices, endogenous. Our model relies on a classical vertical differentiation assumption on the consumer side. In addition, it captures the main effects of coexistence regulation on the production side. GM gene flow is a non-point source pollution and therefore GMO producers do not have the appropriate individual incentives to correct the externality that they exert on non-GM producers (which we model in an extreme way by assuming that GMO producers never undertake any effort to reduce their gene flow unless they are mandated to do so). *Ex ante* technical measures such as isolation distances allow to reduce GM gene flow, and therefore the possible downgrading of some part of their production experienced by non-GM IP producers (we make the restrictive assumption that these producers never undertake any effort on their own to reduce the risk of gene flow). But these technical measures are costly for GMO producers, because they force them to give up the more profitable GMO production on some part of their area. *Ex ante* regulation reduces but does not eliminate the risk of excessive gene flow. *Ex post* compensation to non-GMO producers for their profit losses due to downgrading may be implemented by a public funding and/or by the revenue generated by a GM seed tax.

The literature on the economic analysis of law generally recommands a combination of *ex ante* and *ex post* regulatory instruments. Our results are not in accordance with this general finding. On the contrary, we find with our model that *ex ante* technical measures may be welfare increasing as long as consumers care enough for non-GM goods and as long as GMO cost reductions and IP handling overcosts are modest, but that *ex post* regulation can only deteriorate welfare, whether its funding is public or through a tax on GM seeds.

Further analysis could usefully analyze how robust is this result. Notably, our model is very simple on the production side, with all producers being identical. As a consequence, in the type of equilibrium that is of interest for us, that is, the one where GM and non-GM IP goods coexist, all producers are indifferent between their two possible production choices, which are either GMO production combined with mandatory technical measures, or non-GM production with some probability of harvest downgrading. The proportion of producers that enter into each production type is determined by consumers' demand. As a consequence, with our two possible implementations of *ex post* regulation, every producer suffers a profit loss due to such regulation - while it would be more realistic to make it possible that IP producers benefit from *ex post* regulation. This extension could be performed by introducing some heterogeneity among farmers on the overcost of IP production c_i. It is left for future research.

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A Appendixes

A.1 Proof of Proposition 1

Supply and demand functions imply 6 possible equilibrium cases to consider with labeling ($s < 1$) and ex ante regulation ($e \geq 0$) when no *ex post* regulation is in place ($L = 0$), given that

$$\begin{aligned} \alpha^g &= p_r - (1-e)w - ec_n; \\ \alpha^n &= p_i - c_i - c_n - (p_i - c_i - p_r)(1-e)(1-s)Ind(Q_g). \end{aligned}$$

(i). When $\alpha^n > \alpha^g$ and $\theta^r < \theta^i$, equilibrium conditions ((a)-(d)) imply that:

$$\begin{cases} \widetilde{\theta} = & \theta^r \\ \alpha^n = & 1 - \widetilde{\theta} \\ Q_g = & 0 \end{cases}$$

But, $\widetilde{\theta} = \theta^r \Leftrightarrow \theta^i = \theta^r$, which is in contradiction with the condition $\theta^r < \theta^i$.

(ii). When $\alpha^n > \alpha^g$ and $\theta^r \geq \theta^i$, equilibrium conditions ((a)-(d)) imply that:

$$\begin{cases} \alpha^n = & 1 - \theta^i \\ Q_g = & 0 \end{cases}$$

Only the IP good is produced and consumed and the equilibrium IP good price is $p_i = \frac{1-\delta s}{2-\delta s}(1 + c_n + c_i)$. The welfare is then

$$W_0 = \int_0^{\alpha^n} (p_i - c_i - c_n - \alpha)d\alpha + \int_{\theta^i}^1 (\theta(1-\delta s) - p_i)d\theta = \frac{(1 - \delta s - c_i - c_n)^2}{2(2-\delta s)}.$$

It remains to verify the equilibrium conditions:

- $\alpha^n > \alpha^g \Leftrightarrow p_r < \frac{1-\delta s}{2-\delta s}(1 + c_n + c_i) - (1-e)(c_n - w) - c_i$.

- $\theta^r \geq \theta^i \Leftrightarrow p_r \geq \frac{1-\delta}{2-\delta s}(1+c_n+c_i)$.

  These two conditions on p_r imply that

$$[(1-e)(2-\delta s)-\delta(1-s)]c_n-(1-e)(2-\delta s)w+c_i(2-\delta)<\delta(1-s). \quad (\mathrm{C4}_0)$$

- $\theta^i < 1 \Leftrightarrow c_i + c_n < 1-\delta s$. (C5)

(iii). When $\alpha^n = \alpha^g$ and $\theta^r < \theta^i$, equilibrium conditions ((a)-(d)) imply that:

$$\begin{cases} \alpha^n = & \alpha^g \\ \alpha^g = & 1-\theta^r \end{cases}$$

The two types of goods are produced and consumed and the equilibrium prices are:

$$\begin{aligned} p_r &= \frac{1-\delta}{2-\delta}(1+(1-e)w+ec_n) \\ p_i &= \frac{1-\delta}{2-\delta}(1+(1-e)w+ec_n)+\frac{(1-e)(c_n-w)}{1-(1-e)(1-s)}+c_i \end{aligned}$$

The welfare is then

$$\begin{aligned} W_0 &= \int_0^{\alpha^g}(p_r-ec_n-(1-e)w-\alpha)d\alpha+\int_{\theta^r}^{\widetilde{\theta}}(\theta(1-\delta)-p_r)d\theta+\int_{\widetilde{\theta}}^{1}(\theta(1-\delta s)-p_i)d\theta \\ &= \frac{1}{2}\Bigg[-2\,c_i-\delta s+\frac{-2\,c_n\,(1-e(1-s)(1-e))+2w\,((1-e)-(e+s-es))}{e+s-es} \\ &\quad +\frac{(1+c_n\,e+w)^2-(ew)^2}{2-\delta}+\frac{((1-e)w-(1-e)c_n-(e+s-es)c_i)^2}{(1-s)\,(e+s-e\,s)^2\,\delta}\Bigg] \end{aligned}$$

It remains to verify the equilibrium conditions:

- $\widetilde{\theta} \leq 1 \Leftrightarrow \delta(1-s) \geq \frac{(1-e)(c_n-w)}{1-(1-e)(1-s)}+c_i$. $(\mathrm{C1}_0^-)$
- $\theta^r < \theta^i \Leftrightarrow \delta(1-s) < \frac{2-\delta}{1+(1-e)w+ec_n}\left[\frac{(1-e)(c_n-w)}{1-(1-e)(1-s)}+c_i\right]$. $(\mathrm{C2}_0)$

The conditions $(\mathrm{C1}_0^-)$ and $(\mathrm{C2}_0)$ imply that $(1-e)w+ec_n<1-\delta$.

(iv). When $\alpha^n = \alpha^g$ and $\theta^r \geq \theta^i$, equilibrium conditions ((a)-(d)) imply that:

$$\begin{cases} \alpha^n = & \alpha^g \\ \alpha^g = & 1-\theta^i \\ Q_g = & 0 \end{cases}$$

Only the IP good is produced and consumed and the equilibrium IP good price is $p_i = \frac{1-\delta s}{2-\delta s}(1+c_n+c_i)$. The welfare is then

$$W_0 = \int_0^{\alpha^n} (p_i - c_i - c_n - \alpha) d\alpha + \int_{\theta^i}^1 (\theta(1-\delta s) - p_i) d\theta = \frac{(1-\delta s - c_i - c_n)^2}{2(2-\delta s)}.$$

It remains to verify the equilibrium conditions:

- $\theta^r \geq \theta^i \Leftrightarrow [(1-e)(2-\delta s) - \delta(1-s)]c_n - (1-e)(2-\delta s)w + c_i(2-\delta) \leq \delta(1-s)$ $\quad$ (C4$_0$)
- $\theta^i < 1 \Leftrightarrow c_i + c_n < 1 - \delta s.$ $\quad$ (C5)

(v). When $\alpha^n < \alpha^g$ and $\theta^r < \theta^i$, equilibrium conditions ((a)-(d)) imply that:

$$\begin{cases} \alpha^g = & \widetilde{\theta} - \theta^r \\ \widetilde{\theta} = & 1 \end{cases}$$

Only the GM good is produced and consumed and the equilibrium regular good price is $p_r = \frac{1-\delta}{2-\delta}(1 + (1-e)w + ec_n)$. The welfare is then

$$W_0 = \int_0^{\alpha^g} (p_r - (1-e)w - ec_n - \alpha) d\alpha + \int_{\theta^r}^1 (\theta(1-\delta) - p_r) d\theta = \frac{(1-\delta-(1-e)w - ec_n)^2}{2(2-\delta)}.$$

It remains to verify the equilibrium conditions:

- $\alpha^n < \alpha^g \Leftrightarrow \delta(1-s) < \frac{(1-e)(c_n - w)}{1-(1-e)(1-s)} + c_i;$ $\quad$ (C1$_0^+$)
- $\theta^r < \theta^i \Leftrightarrow (1-e)w + ec_n < 1 - \delta.$ $\quad$ (C3$_0$)

  The condition (C3$_0$) guarantees also that $\alpha^g > 0$.

(vi). When $\alpha^n < \alpha^g$ and $\theta^r \geq \theta^i$, equilibrium conditions ((a)-(d)) imply that:

$$\begin{cases} \alpha^g = & 0 \\ \theta^i = & 1 \end{cases}$$

There is no production at all.

A.2 Proof of Proposition 3

Supply and demand functions imply 6 possible equilibrium cases to consider with labeling ($s < 1$) and ex ante regulation ($e \geq 0$) when *ex post* regulation is in place ($L = 1$), given that

$$\begin{aligned} \alpha^g &= p_r - (1-e)w - ec_n - (1-e)t; \\ \alpha^n &= p_i - c_i - c_n. \end{aligned}$$

(i). When $\alpha^n > \alpha^g$ and $\theta^r < \theta^i$, equilibrium conditions ((a)-(d)) imply that:

$$\begin{cases} \widetilde{\theta} = & \theta^r \\ \alpha^n = & 1 - \widetilde{\theta} \\ Q_g = & 0 \end{cases}$$

But, $\widetilde{\theta} = \theta^r \Leftrightarrow \theta^i = \theta^r$, which is in contradiction with the condition $\theta^r < \theta^i$.

(ii). When $\alpha^n > \alpha^g$ and $\theta^r \geq \theta^i$, equilibrium conditions ((a)-(d)) imply that:

$$\begin{cases} \alpha^n = & 1 - \theta^i \\ Q_g = & 0 \end{cases}$$

Only the IP good is produced and consumed and the equilibrium IP good price is $p_i = \frac{1-\delta s}{2-\delta s}(1 + c_n + c_i)$. The welfare is then

$$W_0 = \int_0^{\alpha^n} (p_i - c_i - c_n - \alpha)d\alpha + \int_{\theta^i}^1 (\theta(1 - \delta s) - p_i)d\theta = \frac{(1 - \delta s - c_i - c_n)^2}{2(2 - \delta s)}.$$

It remains to verify the equilibrium conditions:

- $\alpha^n > \alpha^g \Leftrightarrow p_r < 1 + ec_n + (1 - e)(t + w) - \frac{1+c_n+c_i}{2-\delta s}$.
- $\theta^r \geq \theta^i \Leftrightarrow p_r \geq \frac{1-\delta}{2-\delta s}(1 + c_n + c_i)$.

  These two conditions on p_r imply that

  $$[(1-e)(2-\delta s)-\delta(1-s)]c_n-(1-e)(2-\delta s)(t+w)+c_i(2-\delta) < \delta(1-s). \quad (C4_1^-)$$

- $\theta^i < 1 \Leftrightarrow c_i + c_n < 1 - \delta s. \quad$ (C5)

(iii). When $\alpha^n = \alpha^g$ and $\theta^r < \theta^i$, equilibrium conditions ((a)-(d)) imply that:

$$\begin{cases} \alpha^n = & \alpha^g \\ \alpha^g = & 1 - \theta^r \end{cases}$$

The two types of goods are produced and consumed and the equilibrium prices are:

$$\begin{aligned} p_r &= \frac{1-\delta}{2-\delta}(1 + (1 - e)(w + t) + ec_n) \\ p_i &= \frac{1 - \delta - (1 - e)(w + t) - ec_n}{2 - \delta} + c_n + c_i \end{aligned}$$

The welfare is then

$$
\begin{aligned}
W_0 &= \int_0^{\alpha^n} (p_i - c_n - c_i - \alpha) d\alpha + \int_{\theta^r}^{\widetilde{\theta}} (\theta(1-\delta) - p_r) d\theta + \int_{\widetilde{\theta}}^{1} (\theta(1-\delta s) - p_i) d\theta \\
&= \frac{1}{2}\Bigg[-2\, c_i - s\,\delta + \frac{c_i^2}{\delta(1-s)} + \frac{-2\, c_n\ (1 - e(1-s)(1-e)) + 2w(1-e)^2(1-s)}{e+s-es} \\
&\quad + \frac{(1+ec_n+(1-e)w)^2 - ((1-e)t)^2}{2-\delta} + \frac{2\, c_i(1-e)(c_n-w)}{(1-s)\delta(e+s-es)} \\
&\quad + \frac{(1-e)^2\ (c_n-t-w)\,(c_n(2-e-s+es) + s\,t - w(2-s) + e(1-s)(t+w))}{(1-s)\delta(e+s-es)}\Bigg]
\end{aligned}
$$

It remains to verify the equilibrium conditions:

- $\widetilde{\theta} \leq 1 \Leftrightarrow \delta(1-s) \geq (1-e)(c_n - w - t) + c_i. \quad (\mathrm{C1}_1^-)$
- $\theta^r < \theta^i$
  $\Leftrightarrow \quad \delta(1-s) < \frac{2-\delta}{1+(1-e)(w+t)+ec_n}\,[(1-e)(c_n-w-t)+c_i]$
  $\Leftrightarrow \quad [(1-e)(2-\delta s) - \delta(1-s)e]c_n - (1-e)(2-\delta s)(w+t) + c_i(2-\delta) \leq \delta(1-s) \qquad (\mathrm{C4}_1^+)$

The conditions $(\mathrm{C1}_1^-)$ and $(\mathrm{C4}_1^+)$ imply that $(1-e)(w+t) + ec_n < 1-\delta$.

(iv). When $\alpha^n = \alpha^g$ and $\theta^r \geq \theta^i$, equilibrium conditions ((a)-(d)) imply that:

$$
\begin{cases}
\alpha^n = & \alpha^g \\
\alpha^g = & 1-\theta^i \\
Q_g = & 0
\end{cases}
$$

Only the IP good is produced and consumed and the equilibrium IP good price is $p_i = \frac{1-\delta s}{2-\delta s}(1 + c_n + c_i)$. The welfare is then

$$
W_0 = \int_0^{\alpha^n} (p_i - c_i - c_n - \alpha) d\alpha + \int_{\theta^i}^{1} (\theta(1-\delta s) - p_i) d\theta = \frac{(1-\delta s - c_i - c_n)^2}{2(2-\delta s)}.
$$

It remains to verify the equilibrium conditions:

- $\theta^r \geq \theta^i \Leftrightarrow [(1-e)(2-\delta s) - \delta(1-s)]c_n - (1-e)(2-\delta s)(w+t) + c_i(2-\delta) \leq \delta(1-s) \quad (\mathrm{C4}_1^-)$
- $\theta^i < 1 \Leftrightarrow c_i + c_n < 1 - \delta s. \quad (\mathrm{C5})$

(v). When $\alpha^n < \alpha^g$ and $\theta^r < \theta^i$, equilibrium conditions ((a)-(d)) imply that:

$$
\begin{cases}
\alpha^g = & \widetilde{\theta} - \theta^r \\
\widetilde{\theta} = & 1
\end{cases}
$$

Only the GM good is produced and consumed and the equilibrium regular good price is $p_r = \frac{1-\delta}{2-\delta}(1 + (1-e)(w+t) + ec_n)$. The welfare is then

$$W_0 = \int_0^{\alpha^g} (p_r - (1-e)(w+t) - ec_n - \alpha)d\alpha + \int_{\theta^r}^1 (\theta(1-\delta) - p_r)d\theta = \frac{(1-\delta-(1-e)(w+t)-ec_n)^2}{2(2-\delta)}.$$

It remains to verify the equilibrium conditions:

- $\alpha^n < \alpha^g \Leftrightarrow \delta(1-s) < (1-e)(c_n - w - t) + c_i;\quad (\mathrm{C}1_1^+)$
- $\theta^r < \theta^i \Leftrightarrow (1-e)(w+t) + ec_n < 1-\delta.\quad (\mathrm{C}3_1)$

  The condition $(\mathrm{C}3_1)$ guarantees also that $\alpha^g > 0$.

(vi). When $\alpha^n < \alpha^g$ and $\theta^r \geq \theta^i$, equilibrium conditions ((a)-(d)) imply that:

$$\begin{cases} \alpha^g = & 0 \\ \theta^i = & 1 \end{cases}$$

There is no production at all.

A.3 Study of conditions

Conditions can be rewritten to express the restrictions on the cost parameter when $e < \frac{2-\delta}{2-\delta s}$. This allows us to represent the equilibria.

- $(\mathrm{C}1_0^-) \Leftrightarrow c_n \leq w + \frac{(e+s-es)[(1-s)\delta - c_i]}{1-e} = C10$.

  The function $C10$ is increasing in e when $c_i < \delta(1-s)$, which is equivalent to $c_n > w$.

- $(\mathrm{C}2_0) \Leftrightarrow c_n > \frac{\delta(1-s)(e+s-es)+[\delta(1-s)(e+s-es)+2-\delta](1-e)w-(2-\delta)(e+s-es)c_i}{(2-\delta)(1-e)-\delta(1-s)e(e+s-es)} = C20$.

  The function $C20$ is increasing in e when $c_i < \frac{\delta(1-s)(1+w)}{2-\delta}$.

- $(\mathrm{C}3_0) \Leftrightarrow c_n < \frac{1-\delta-(1-e)w]}{e} = C30$.

  The function $C30$ is decreasing in e when $1-\delta > w$.

- $(\mathrm{C}4_0) \Leftrightarrow c_n \leq \frac{\delta(1-s)+(2-\delta s)(1-e)w-(2-\delta)c_i}{(2-\delta s)(1-e)-\delta(1-s)} = C40$.

  The function $C40$ is increasing in e when $c_i < \frac{\delta(1-s)(1+w)}{2-\delta}$.

- $(\mathrm{C}5) \Leftrightarrow c_n \leq 1 - \delta s - c_i = C5$.

- $(\mathrm{C}1_1^-) \Leftrightarrow c_n \leq w + t + \frac{(1-s)\delta - c_i}{1-e} = C11$

  The function $C11$ is increasing in e when $c_i < \delta(1-s)$, which is equivalent to $c_n > w + t$.

- $(\mathrm{C3}_1) \Leftrightarrow c_n < \frac{1-\delta-(1-e)(w+t)]}{e} = C31$.

  The function $C31$ is decreasing in e when $1-\delta > w+t$.

- $(\mathrm{C4}_1^+) \Leftrightarrow c_n > \frac{\delta(1-s)+(2-\delta s)(1-e)(w+t)-(2-\delta)c_i}{(2-\delta)(1-e)-\delta(1-s)e} = C41$

  The function $C41$ is increasing in e when $c_i < \frac{\delta(1-s)(1+w+t)}{2-\delta}$.

More,

- $C11 = C31 = C41$ when $w = \frac{1-\delta-(1-e)t-e(1-\delta s-c_i)}{1-e} = \widetilde{w}_1$;
- $C10 = C20 = C30$ when $w = \frac{1-\delta-e^2(1-s)((1-s)\delta-c_i-e(1-c_i s-\delta+s\delta-s^2\delta)}{1-e} = \widetilde{w}_0$;
- $C30 = C40 = C50$ when $w = \frac{1-\delta-e(1-\delta s-c_i)}{1-e} = \overline{w}$.

Besides,

- $C11 > C10$;
- $C30 \geq C31$;
- $C40 > C20$ when $c_i < \frac{(1-s)\delta(1+w)}{2-\delta}$.
- $C41 > C20$ when $c_i < \frac{(1-s)\delta(1+w)}{2-\delta} + t\frac{(2-\delta s)[(2-\delta)(1-e)-(1-s)\delta(e+s-es)e])}{(1-e)(1-s)(2-\delta)^2}$.

A.4 Equilibrium Diagrams

Equilibrium diagram when labeling ($s < 1$), ex ante regulation ($e \geq 0$), and no *ex post* regulation ($L = 0$).

Results are different according to the level of IP costs, c_i, relatively to the quality discount, δ.

Equilibrium diagram when labeling ($s < 1$) and *ex ante* as well as *ex post* coexistence regulation ($e \geq 0$, $L = 1$, $t \geq 0$).

with $\delta = 0.5, s = 0.009, c_i = 0.01$, and e = 0.05

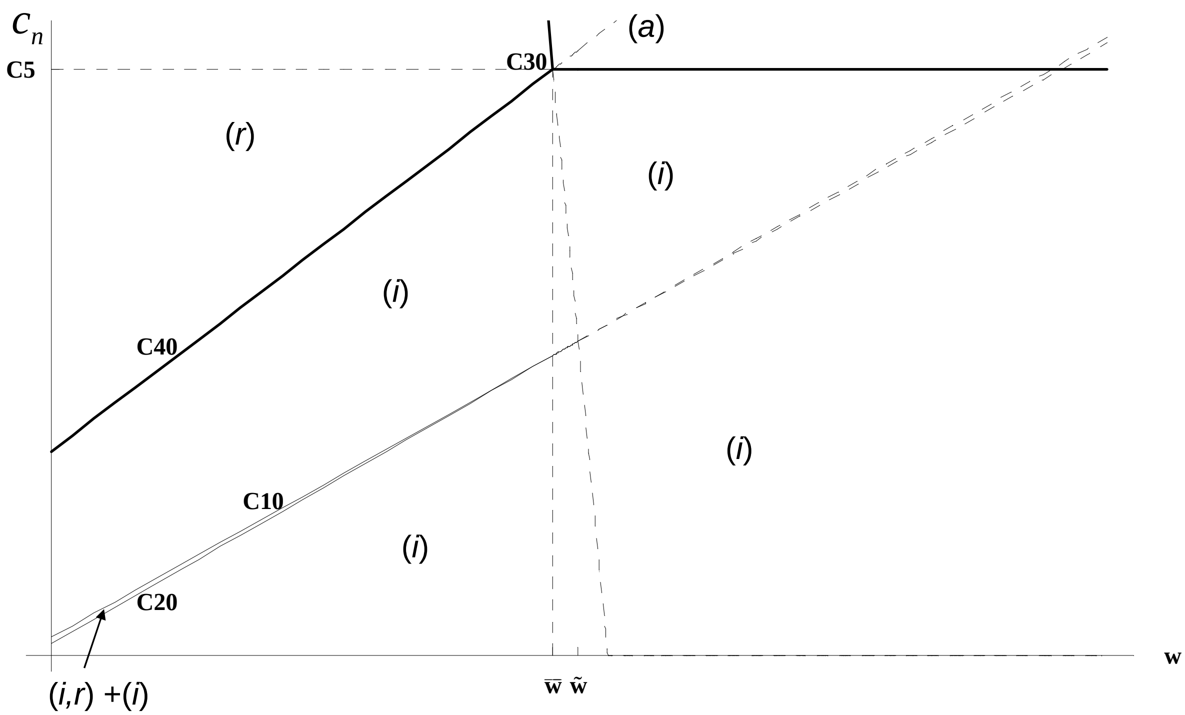

Figure 1: Equilibrium diagram with *ex ante* regulation and c_i low

with $\delta = 0.1, s = 0.009, c_i = 0.25,$ and e $= 0.05$

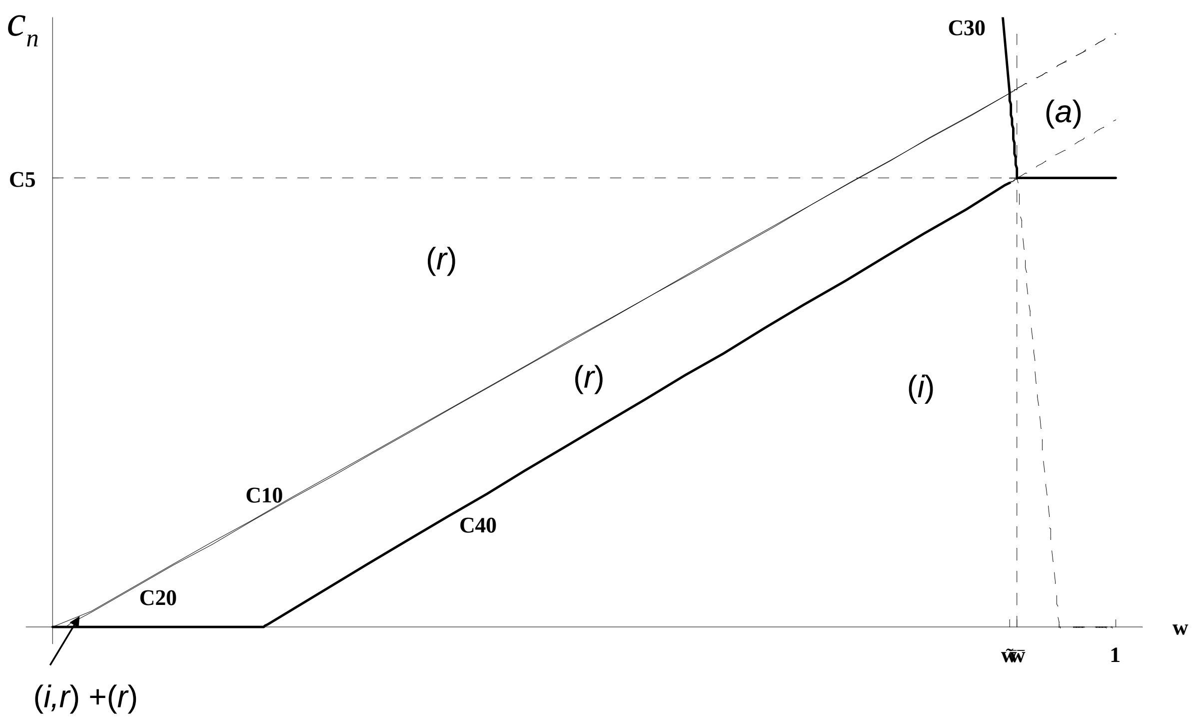

Figure 2: Equilibrium diagram with *ex ante* regulation and c_i high

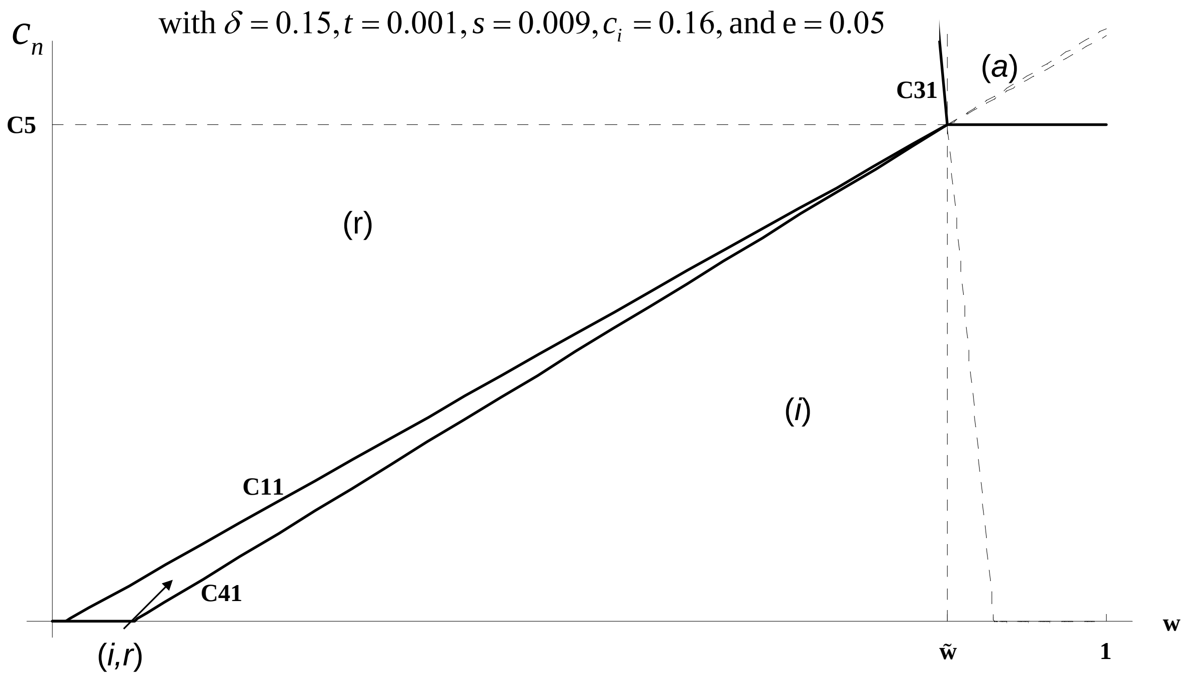

Figure 3: Equilibrium diagram with *ex ante* and *ex post* regulation