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Abstract: Pesticide in vine growing is a strong environmental concern, given the intensive use and the complex pollution nature. We build a model to investigate the potential effects of the introduction of a pesticide tax on the French wine market. First, we examine the theoretical relationship between risk and market power. Then we study the effect of a pesticide tax in an otherwise unregulated oligopoly. Lastly, we study how the tax interferes with public intervention and professional self-regulation that takes place in the sector. We find that the appellation regime fosters the use of pesticide through quantity limitations on grape, as compared to the unregulated situation. This suggests that both types of regulations should be handled together, for example in a single book of specifications.

Keywords: WINE MARKET, PESTICIDE, ENVIRONMENTAL TAXATION, WINE QUALITY, MODELISATION

* This research as benefited from the support of the ANR-ADD program ”Wine and Pesticide”. Both authors were affiliated to INRA when this research was initiated.

Pesticide Regulation: The Case of French Wine*

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Abstract

Pesticide in vine growing is a strong environmental concern, given the intensive use and the complex pollution nature. We build a model to investigate the potential effects of the introduction of a pesticide tax on the French wine market. First, we examine the theoretical relationship between risk and market power. Then we study the effect of a pesticide tax in an otherwise unregulated oligopoly. Lastly, we study how the tax interferes with public intervention and professional self-regulation that takes place in the sector. We find that the *appellation* regime fosters the use of pesticide through quantity limitations on grape, as compared to the unregulated situation. This suggests that both types of regulations should be handled together, for example in a single book of specifications.

1 Introduction

The term pesticide refers to a large family of substance which are used to lesser or prevent damages from a pest. Their use has spread around the world since World War II and permitted an increase in yield and the development of intensive farming. For example, between 1965 and 2005, the average yield for wheat in the world increased by 145%, and pesticides played a major role in that Green Revolution (CNUCED). A by-product of this intensive use is a widespread contamination of the environment. As an illustration, the

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French Environment Institute (IFEN) has detected pesticides in 96% of the running water samples it tested and in 61% of the subterranean waters (IFEN, 2006). Moreover, pesticides are found in the air and can stay for decades in soils (Aubertot et al., 2005). On top of that, pesticides may have effects on human and wildlife health. Even if the very small concentrations makes it difficult to measure contamination and the diversity of active ingredient makes it impossible to measure interactions effects, this pollution has become a great concern for the public powers.

From the environmental economic point of view, pesticide pollution ranges in the category of non-point source pollution. The impossibility of tracking the agents responsible for the emissions forbids the application of the standard pigouvian instruments. For the last decades, this kind of pollution has been widely investigated and a large economic literature exists on this subject. Many solutions have been purposed to regulate it, among which the most notable are a tax on the pollutant input (Plott, 1966), an ambient tax (Segerson, 1988) and taxing a proxy for emissions (Shortle and Dunn, 1986). If each of these instruments has its advantages, only the first and last one have been implemented to our knowledge. Denmark has an important levy on pesticides (Schou and Streibig, 1999) and Netherlands use a proxy for taxing nitrate leaking (Helming, 1998).

Regarding wine production, pesticide use is a problematic issue for at least three reasons. The first one is technical: Vine growing is concentrated in time and space, which prevents the implementation of many alternative agronomic solutions to pesticide use-not to mention crop rotation. The second is historical and sociological: The vine grown are from European species which forbid the culture of resistant species similar to that grown in America. Finally, the third reason is economic: Wine growing is a cash crop, which implies high returns from the use of pesticides. The consequence is that given the climatic conditions favorable to fungi, the vine farmers use 20% of the pesticides sold in France (mainly fungicides), while they represent only 3% of its agricultural surface. Also, the geographic concentration of wine growing (often in regions bordering rivers) exacerbates the hazardous effect of pesticide on the environment, both locally (soil, air and subterranean waters) and globally (running waters and air).

The concerns are not new to the economic and environmental policy debate. But the understanding of environmental and health impact coupled with the economic impact of potential regulation did not lead to consensus. We are concerned in this paper with the economic functioning of the wine market, without describing the environmental effects. In other words, we tend to analyze how regulation (whatever its final objective) would affect the functioning of the market from an industrial economics point of view. The economic impact of pesticide has been subject to both empirical and theoretical debates in the 70's and 80's. Much of the early empirical analysis failed to explain adequately the use of pesticide because of a functional mispecification (a concern raised first in Just and Pope, 1978, 1979). One should indeed distinguish between *productive* and *protective* inputs in agricultural production (Lichtenberg and Zilberman, 1986). Taking this difference into account is in fact necessary to both understand and measure the effect of pesticides, as empirically proved in Antle (1988). This suggests that the right way of modeling pesticide effect is to assume that their application both increases mean and reduces variance of the harvest: By lowering infection probability, higher harvests are indeed more often obtained. However, empirical studies continue to diverge on the estimation on such elementary facts as pest damages and pesticide productivity (see Babcock et al., 1992; Chambers and Lichtenberg, 1994; Carpentier and Weaver, 1997, among others).

On the more theoretical side - the approach taken here, the literature has mostly focus on the attitude towards risks of the farmers and the associated empirical evidence (see e.g. Feder, 1979; Antle, 1987). However, as shown in the seminal paper of Antle (1983b), one may suspect that risk-aversion of the farmers is not necessarily the key element of the analysis. In fact, accounting for sequential decision-making in agricultural production[1], he obtains that risk has an effect on farmers profit even under risk-neutrality, and in particular that producers may want to reduce variance in that context. This is the modeling avenue we follow here. However, the effect of variance that we identify in the present analysis is the consequence of the interplay of disease risk and market power. In the case of French wine, professional self-regulation takes place, which confers (at least at the syndicate level) some market power, and as we show, induces concerns for risk reduction. This is especially true because producers from a given region are aware of the common climatic and disease risks to which they are subject, and because market is segmented enough so that they have some impact on the price (even though globalization of the wine market has tended to soften this effect since a few years).

[1] See also Antle (1983a).

We show that in such a setting producers do use pesticide both for mean-increasing and risk-reducing purpose: the variance of their harvest enter negatively in their objective function. In an unconstrained oligopoly, the more risky production is (both with regard to the severeness of disease and correlation between infection of different producers), the more pesticide they use, and the smaller the maximal harvest they target. Introducing a tax on the pollutant input decreases pesticide use and increases targeted yield for any positive tax level. However, when one accounts adequately for the regulation in place, this is no more true. Professional self-regulation is allowed on the wine market (as well as for some other protected products, see Title IV of the European Council Regulation No 1493/1999). In particular, public authorities together with producers' organizations limit per hectare yield[2] (in fact both through production requirements of the *Appellations* system, in an ex-ante fashion, and ex-post through annual decision). A central result is that the pesticide consumption is not responsive to low taxes level under those circumstances. There is some tax threshold above which the demand for pesticide is not elastic. In addition, somewhat counter-intuitively, restricted yields may lead to higher pesticide intensity and even higher consumptions of pesticides than in absence of regulation. This questions the methods of public action regarding pesticide use under the protected origin regime.

One way of reducing pesticide use without altering two much the quality dimension (the main rationale behind the actual regime) is therefore to undertake a joint reform of environmental and farming regulations. To this end, we discuss potential avenues for reform in the end of the analysis.

The paper is organized as follows. The next section sets up the model and analyze the case of monopoly to illustrate important features of the model. The third section is dedicated to the (otherwise) unregulated market, would the French regulation system not be in place. The fourth section analyzes the interplay between professional self-regulation and pesticide use. The last section concludes.

[2]The rationale behind such a regulation is the interplay between quality and quantity on such markets. See Giraud-Héraud et al. (2003) and Fleckinger (2007) for theoretical analyses and the references therein regarding empirical facts.

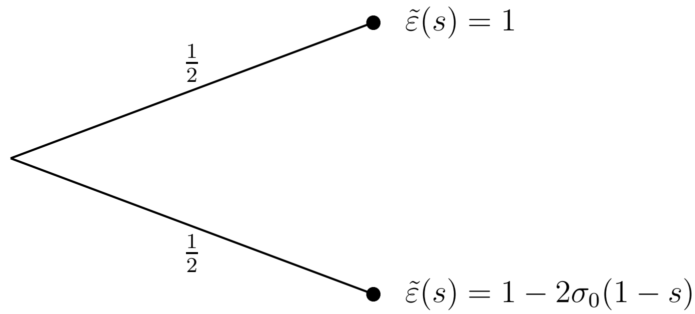

Figure 1: An example of yield risk

2 Model and preliminary example

2.1 The technology: Growing grape

The production technology has two variables: Each producer selects a harvesting capacity, q, and the intensity of pesticide he uses, s, with $0 \leq s \leq 1$. The yield attained with respect to capacity depends on the intensity of pesticide and on the weather, and it is represented by the random variable $\tilde{\varepsilon}(s)$. The realized harvest is therefore:

$$\tilde{q} = q\tilde{\varepsilon}(s) \quad \text{with} \quad 0 \leq \tilde{\varepsilon}(s) \leq 1.$$

We denote by $\varepsilon(s)$ and $\sigma(s)$, respectively the mean and standard deviation of $\tilde{\varepsilon}(s)$. We will assume the following regarding mean and variance:

$$\varepsilon(s) = 1 - \sigma_0(1-s) \quad \text{and} \quad \sigma^2(s) = \sigma_0^2(1-s)^2$$

This corresponds for example to the random variable represented on figure 1. With probability one half, the harvest is healthy, and full yield obtains, while with probability one half, it is plagued by a disease which damage intensity depends on pesticide use. Note that σ_0 is a measure of the natural risk.

Finally, the cost function of a producer depends on the level of production and pesticide intensity as follows:

$$C(\tilde{q}, s) = \underbrace{h\tilde{q}}_{\textit{ex-post}} + \underbrace{c(q-q_0)^2 + (w+t)sq}_{\textit{ex-ante}}$$

where w denotes the unit price of pesticides and t the unit tax. The first term corresponds to the ex-post costs, that depends on the realization of the harvest. The second term corresponds to ex-ante costs at the planning stage, which are a function of the maximal yield which is targeted. This cost depends on the natural yield of the crop, q_0. Targeting a lower harvest is costly, since it requires cutting costs and grape control, while attaining a higher yield requires care, such as foliage reduction. Finally the third term represents the pesticide costs, which is naturally proportional to the maximal level that the farmer is targeting. Indeed, the functioning is as follows: once a given maximal harvest q has been chosen, the intensity of pesticide determines what fraction of this productive capacity is realized. This determines at the same time the variance of the harvest. It is important to keep in mind that while harvesting costs are realized ex-post, the cost of pesticide is paid ex-ante and corresponds to the decision of how much to minimize the loss with respect to a maximal yield. To summarize, pesticides, which cost is paid ex-ante, both reduce the variance and increase the mean of the harvest. Overall, this formulation reflects accurately the technical choice that a producer faces.

2.2 An example: The case of monopoly

To identify some essential features without entering the full market mechanism, we begin by considering the case of monopoly. The (ex-post) inverse demand function is assumed linear, with:

$$p(\tilde{q}) = a - b\tilde{q}$$

Under monopoly, the expected profit writes:

$$\begin{aligned}
\pi_M(q,s) &= \mathbb{E}[p(\tilde{q})\tilde{q} - C(\tilde{q},s)] \\
&= \mathbb{E}[a\tilde{q} - b\tilde{q}^2 - h\tilde{q}] - c(q-q_0)^2 - (w+t)sq \\
&= (a-h)q\varepsilon(s) - bq^2(\varepsilon^2(s) + \sigma^2(s)) - c(q-q_0)^2 - (w+t)sq \qquad (1)
\end{aligned}$$

It is important to notice the effect of the variance on profit, since it is at the heart of the analysis. To this end, consider a world with no risk ($\sigma_0 = 0$), and therefore no need for pesticides. We would have then:

$$\pi_M(q)|_{\sigma_0=0} = (a-h)q - bq^2 - c(q-q_0)^2$$

which is a standard model (possibly up to the quadratic cost part). Comparing with (1), it is clear that, even absent risk-aversion[3], the interplay between risk and market power

[3] Which allows to abstract from difficulties involved in such a case, see Newbery and Stiglitz (1982).

confers a value to risk-reducing inputs, such as pesticides. This is expressed in the term $-bq^2\sigma^2(s)$: variance reduces expected profit. Note that it depends on the pesticide intensity since the variance is a function of s, and on the size of the maximal harvest, q, which reflects in particular the multiplicative nature[4] of climatic risk (Hazell and Scandizzo, 1975).

When developing the monopoly profit, we have a concave function of q and s separately and it can be checked afterwards that the first-order conditions are sufficient. The monopoly solution is such that:

$$\begin{aligned} q_M &= \frac{\sigma_0\Lambda + (1-2\sigma_0)(w+t)}{2\sigma_0(b+2c)} \\ s_M &= \frac{\sigma_0(b\sigma_0\Lambda + (\Lambda - 2(b+2c)q_0)c) - (b(1-\sigma_0)^2 + b\sigma_0^2 + c)(w+t)}{b\sigma_0(\sigma_0\Lambda + (1-2\sigma_0)(w+t))} \\ &\quad \text{where } \Lambda \equiv a - h + 4cq_0 \end{aligned}$$

It can be shown that the monopoly reacts to an increase in σ_0 by increasing s_M, the pesticide intensity, and decreasing q_M. Also, increasing the tax leads to a decrease in pesticide intensity, but increases q_M. Overall, the total use of pesticide, $s_M q_M$, is decreasing in t. In the following, we will see that these intuitive properties carry on to the unregulated market, but not necessarily to the regulated market, where maximal yields are constrained.

3 Unconstrained oligopoly

3.1 The market

There is overall a set of n ex-ante identical producers, indexed by i, each equipped with the technology described above. We assume that the demand function is an instantaneous demand function, which amounts to exclude the possibility of stock[5]. The interaction results in the total production:

$$\tilde{Q} = \sum_i \tilde{q}_i.$$

[4] That is, between production scale and climatic hazard.

[5] It is however relevant to study pesticide regulation in combination with stock control. This should be the subject of further investigation, which would straddle two strands of literature, namely environmental regulation and commodity price stabilization, in the spirit of Newbery and Stiglitz (1981).

We stick to the linear demand function of the monopoly case, so that:

$$p(\tilde{Q}) = a - b\tilde{Q}.$$

We also need the following notations: $\tilde{Q}_{-i} \equiv \sum_{j \neq i} \tilde{q}_j$, $\tilde{\varepsilon}_i \equiv \tilde{\varepsilon}_i(s_i)$ and $\sigma_i \equiv \sigma_\varepsilon(s_i)$. We have to take into account that the weather generates correlated randomness for the producers. We assume that the correlation between $\tilde{\varepsilon}_i$ and $\tilde{\varepsilon}_j$ is ρ, so that :

$$Cov(\tilde{q}_i, \tilde{q}_j) = \rho \sigma_i \sigma_j q_i q_j$$

for all i, j and s_i, s_j. The expected profit is therefore overall given by:

$$\pi_i(q_i, s_i) = \mathbb{E}[p(\tilde{Q})\tilde{q}_i - C(\tilde{q}_i, s_i)] \tag{2}$$

In the following, we will need a proper expression of this expectations, and in particular an expression of the expected turnover of producer i. We have:

$$\begin{aligned}
\mathbb{E}[p(\tilde{Q})\tilde{q}_i] &= \mathbb{E}[(a - b\tilde{Q})\tilde{q}_i] \\
&= a\mathbb{E}[\tilde{q}_i] - b\mathbb{E}\left[\tilde{q}_i^2 + \tilde{q}_i \tilde{Q}_{-i})\right] \\
&= aq_i\varepsilon_i - bq_i^2(\varepsilon_i^2 + \sigma_i^2) - b\sum_{j \neq i} q_i q_j(\varepsilon_i \varepsilon_j + \rho \sigma_i \sigma_j)
\end{aligned}$$

Importantly, we observe the presence of the risk-premium associated with the fact that production is stochastic. This effect, already observed in the monopoly case, is here more complicated, as expressed in the terms containing ρ and the σ_i's. It does not exist in standard Cournot models. Note finally that the assumption of a linear inverse demand is not essential: any concavity of the producer profit in own quantity is the root of those effects of risk.

We consider symmetric equilibria in the following, so that $\varepsilon_j = \varepsilon_k = \varepsilon$, $q_j = q_k = q$ and $\sigma_j = \sigma_k = \sigma$ for all j and k different from i. We obtain the following expression of turnover:

$$\mathbb{E}[p(\tilde{Q})\tilde{q}_i] = aq_i\varepsilon_i - bq_i^2(\varepsilon_i^2 + \sigma_i^2) - (n-1)bq_i q(\varepsilon\varepsilon_i + \rho\sigma\sigma_i)$$

We also assume that the cost c is negligible, i.e. we set $c = 0$. The following definitions will be useful:

$$\begin{aligned}
\Phi &\equiv \sigma_0^2(2 + (n-1)\rho) \\
\Psi &\equiv \sigma_0^2(4 + (n-1)(1+\rho))
\end{aligned}$$

3.2 Market Equilibrium and Risk

We define the limit tax, i.e. the tax level above which the producers decide to forego pesticide use:

$$t^u \equiv \frac{\Phi(a-h)}{(n+1)(1-2\sigma_0)+\Psi} - w$$

Solving for the equilibrium yields the next proposition.

Proposition 1 *The symmetric equilibrium of the oligopoly is characterized by:*

$$\begin{cases} q_n^* &= \frac{\Phi(a-h)+((n+1)\sigma_0-\Psi)(w+t)}{b(n+1)\Phi} \\ s_n^* &= 1-\frac{(n+1)(1-\sigma_0)(w+t)}{\Phi(a-h)+((n+1)\sigma_0-\Psi)(w+t)} \end{cases} \qquad \textit{when} \quad t \le t^u$$

$$\begin{cases} q_n^* &= \frac{(a-h)(1-\sigma_0)}{b(\Psi+(n+1)(1-2\sigma_0))} \\ s_n^* &= 0 \end{cases} \qquad \textit{when} \quad t > t^u$$

Up to some tax level, the producers react to the tax by using less pesticides, and abandon them for high enough tax levels. We are first interested in the effect of risk. For the interior equilibrium, the following comparative statics hold:

Lemma 1 *An increase in the risk parameters σ_0 and ρ:*

- *Decreases the maximal quantity:* $\frac{\partial q_n^*}{\partial \sigma_0}, \frac{\partial q_n^*}{\partial \rho} < 0$
- *Increases pesticide intensity:* $\frac{\partial s_n^*}{\partial \sigma_0}, \frac{\partial s_n^*}{\partial \rho} > 0$
- *Increases total pesticide use:* $\frac{\partial}{\partial \sigma_0}(q_n^* s_n^*), \frac{\partial}{\partial \rho}(q_n^* s_n^*) > 0$

Proof. We have:

$$\frac{\partial q_n^*}{\partial \sigma_0} = \frac{-(w+t)}{b\Phi} < 0$$
$$\frac{\partial q_n^*}{\partial \rho} = \frac{-(n-1)\sigma_0^3(1-\sigma_0)(w+t)}{b\Phi} < 0$$

which says that the riskier and the more stochastically interdependent are productions, the less is produced. Also, we have:

$$\frac{\partial s_n^*}{\partial \sigma_0} = \frac{(n+1)(w+t)[(2-\sigma_0)(\Phi(a-h)-\Psi(w+t))+(n+1)\sigma_0(w+t)]}{\sigma_0(\Phi(a-h)-(\Psi-(n+1)\sigma_0)(w+t))^2} > 0$$
$$\frac{\partial s_n^*}{\partial \rho} = \frac{(n^2-1)\sigma_0^2(a-h-w-t)(w+t)}{(\Phi(a-h)-(\Psi-(n+1)\sigma_0)(w+t))^2} > 0$$

And finally:

$$\frac{\partial}{\partial \sigma_0}(q_n^* s_n^*) = \frac{2\sigma_0(1-\sigma_0)(w+t)}{b\Phi} > 0$$
$$\frac{\partial}{\partial \rho}(q_n^* s_n^*) = \frac{(n-1)\sigma_0^2(1-\sigma_0)^2(w+t)}{b\Phi^2} > 0$$

■

3.3 The effect of the Tax

The following holds regarding the effect of the tax on the two decision variables:

Lemma 2 *The effect of an increase of the tax is to decrease the intensity of pesticide, to increase maximal quantity and to overall decrease pesticide use.*

Proof. Simple calculations yield:

$$\frac{\partial q_n^*}{\partial t} = \frac{(n+1)\sigma_0 - \Psi}{b(n+1)\Phi}$$

Since $\Psi = \sigma_0^2(4 + (n-1)(1+\rho))$, we have to study the sign of:

$$(n+1)\sigma_0 - \Psi = \sigma_0[-(n+1)\sigma_0\rho + (n+1) - (n+3)\sigma_0)]$$

The derivative with respect to ρ is $-(n-1)\sigma_0^2 \leq 0$, so that the minimum is attained for $\rho = 1$, where the value is $\sigma_0(n+1)(1-2\sigma_0) > 0$.
For pesticide intensity, we have directly:

$$\frac{\partial s_n^*}{\partial t} = \frac{-(n+1)(1-\sigma_0)\Phi(a-h)}{(\Phi(a-h) - (\Psi - (n+1)\sigma_0)(w+t))^2} < 0$$

And finally, as regards total pesticide quantity, we obtain:

$$\frac{\partial}{\partial t}(s_n^* q_n^*) = \frac{-((n+1)(1-2\sigma_0) + \Psi)}{b(n+1)\Phi} < 0$$

■

4 The book of specifications

In the French *Appellations* regime, producers have to conform to some established rules, regarding maximal yield and process constraints so as to benefit from a premium on a top market segment. In the model, we introduces this in the form of a constraint on q, the maximal per hectare yield. In reality, producers are indeed restricted to some output level per hectare, noth ex-ante through pre-specified technical pathes and ex-post through limited selling yields at the time of harvest. We denote by r the ex-ante restriction and $\overline{q}$ the ex-post constraint.

4.1 The ex-ante constraint

We first consider the case in which there is only an ex-ante constraint on the maximal yield, which represents a shortcut for the imposed agronomic practices. From an empirical point of view, this is the variable most responsible for the quality of the grape, in the technical quality vs quantity trade-off. For this constraint to be effective, we assume that the limit yield r is sufficiently small, that is, we assume:

$$r < q_n^* \qquad and \qquad r < q_0$$

This is line with reality. In particular, the second inequality represents the real agronomic constraint: the vineyard could indeed produce more than the constraint imposed in the AOC requirements. It is easily shown that the producers will choose exactly $q = r$, and only optimize with respect to the intensity of pesticides they use. This yields the following solution:

$$s_n^r = 1 - \frac{w + t - \sigma_0(a - h - (n+1)br)}{rb\Psi}$$

when interior, that is when

$$\sigma_0(a - h - (n+1)br) < w + t < \sigma_0(a - h - (n+1)br) + br\Psi \tag{3}$$

This defines a range $0 < \underline{t}^a < t < \overline{t}^a$.

Put differently, producers use full pesticide intensity as soon as:

$$r \leq \frac{\sigma_0(a - h) - (w + t)}{(n+1)b\sigma_0} \equiv r^l$$

in such a case, the production is so valuable that maximal use of pesticide obtains. This is in contrast to proposition 1, where the producers never used such a pesticide intensity,

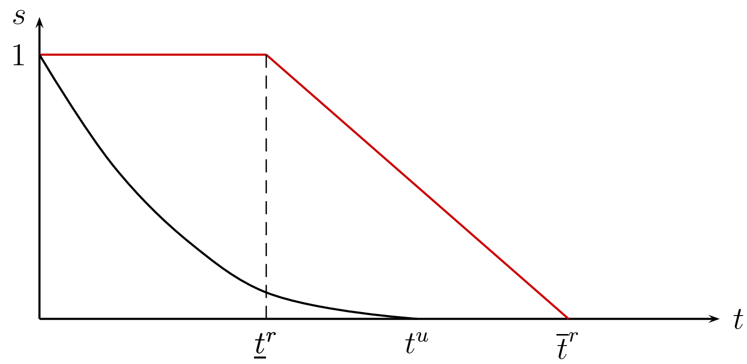

Figure 2: Tax responsiveness

and rather preferred to increase maximal quantity.
In that case of ex-ante regulation of quantities, the effect of tax is particularly simple. In the range defined by (3), increasing the tax decreases pesticide intensity, and since quantity is blocked, this also directly reduce pesticides quantity. Outside this range, modifying the tax has no effect.

Comparing with the unconstrained case is instructive. Indeed, we have:

$$t^u - \overline{t}^r = \frac{((n+1)\sigma_0 - \Psi)(r - q_n^*(t^u))}{b((n+1)(1-2\sigma_0)+\Psi)^2} < 0$$

where the last inequality comes from the assumption of constraining specifications (otherwise we trivially have $t^u = \overline{t}^r$).

A typical situation is pictured on figure 2.

It is now worth identifying the overall effect on pesticide use of the constraint $q \leq r$. To do this, we need to compare $s_n^* q_n^*$ and $s_n^r r$. Using calculations of lemma 2, it is straightforward to obtain:

$$\frac{\partial}{\partial r}(s_n^r r) = 1 - \frac{(n+1)\sigma_0}{\Psi} < 0$$

when $0 < s^r < 1$. In turn, if $s^r = 1$, it is clear that the total quantity of pesticide is increasing in r. Therefore we can state:

Proposition 2 *The effect of the constraint $q \leq r$ of the book of specification is non-monotonic. For low values of r, the pesticide intensity is maximal ($s_n^r = 1$) and therefore total pesticide quantity increases. Then, after some point r^l, s_n^r is no more maximal and total pesticide use decreases.*

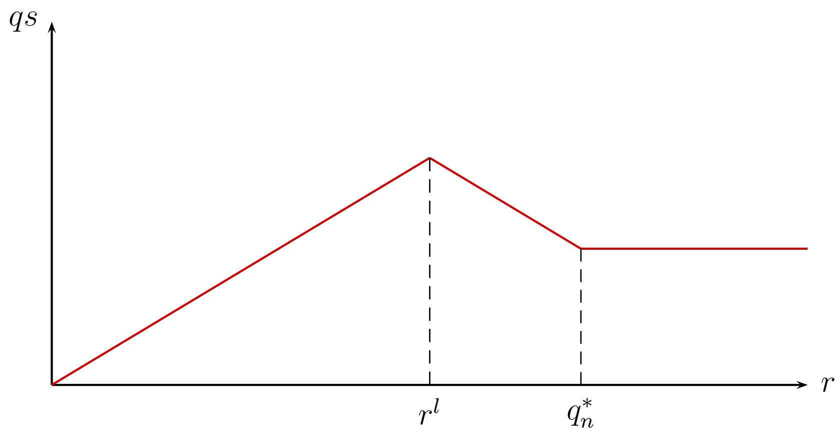

Figure 3: Effect of the ex-ante specification

This result is illustrated in figure 3.

4.2 The ex-post constraint

The present regulation on the French wine market relies on a limit on the saleable harvest and not on the maximal yield. This limit harvest is enforced ex-post, in the sense that the producers are not allowed to sell more that some level $\bar{q}$. This is equivalent in terms of profit to a harvest that is limited to $\bar{q}$ for all cases in which $\tilde{q} > \bar{q}$. Now, in optimizing with respect to q and s, the producers will thus have to consider a modified random variable, instead of the true harvest. We will consider that the physical harvest is the random variable represented on the first figure. Also, to make the constraint binding, we assume:

$$\bar{q} < q_n^*$$

There will be two kinds of strategy that can be relevant. Either the producers target a maximal harvest exactly equal to $\bar{q}$, in which case there will never be any overcapacity, or they can target a higher yield, in which case the whole realized harvest may in fact not be sold. The first case is formally identical to that of an ex-ante constraint, and we have therefore already studied it. In turn, the second case requires some further steps, since different subcases may occur.

4.2.1 Targeting a sure sales level

Provided producers choose a sure harvest, the market benefits are fixed, and we can restrict attention to the sole costs. Among the strategies that yield some level of harvest for sure, we can clearly restrict to the one such that the realized is exactly the maximal one (otherwise the constraint would not be binding). To do that, a producer can either set $s = 1$ and $q = \overline{q}$, or set some $s < 1$ and $q > \overline{q}$, such that $(1 - 2\sigma_0(1 - s))q \geq \overline{q}$, which means that in the worst case, the harvest is exactly $\overline{q}$. Which one of these strategies is the best one depends of course on the pesticides' price and tax. The corresponding cost minimization problem writes:

$$\begin{aligned} \underset{q,s}{Min} \qquad & h\overline{q} + (w+t)sq + c(q-q_0)^2 \\ s.t. \qquad & q - 2\sigma_0(1-s) \geq \overline{q} \end{aligned}$$

To solve this program, we will have to analyze different cases.

Case 1: $\overline{q} \leq q_0 - 2\sigma_0$. In that case, the producer can simply let his harvest grow, and is sure to obtain, even in the worst case, the maximal authorized yield. This therefore costs him nothing ex-ante. Of course, this is not a realistic case. In other words, the difference $q_0 - \overline{q}$ is not that large, or at least the perception of σ_0 by the producers does not correspond to such a situation. Therefore we discard this possibility in the following.

Case 2: $\overline{q} > q_0 - 2\sigma_0$. In that case, the producer must incur either an agronomic cost (through the quadratic cost), or use pesticides to obtain $\overline{q}$ for sure. This means that the constraint will be binding, so that we can substitute it in the objective. For example, substituting s yields:

$$\begin{aligned} C(q, 1 - \frac{q-\overline{q}}{2\sigma_0 q}) &= h\overline{q} + (w+t)(1 - \frac{q-\overline{q}}{2\sigma_0 q})q + c(q-q_0)^2 \\ &= h\overline{q} + (w+t)\frac{\overline{q} - (1-2\sigma_0)q}{2\sigma_0} + c(q-q_0)^2 \end{aligned}$$

Note that in any case, the producer will choose $q \geq q_0$. Indeed, targeting a lower yield will be more costly, for a lowest probability of attaining $\overline{q}$. This indicates clearly that only the ex-ante constraint may properly resolve the technical quality vs quantity trade-off. In fact, this is indeed the case in the AOC requirements.

Minimizing the costs in that second case yields the optimal quantity:

$$q = q_0 + \frac{(w+t)(1-2\sigma_0)}{4c\sigma_0}$$

Clearly the optimal quantity is increasing in $(w+t)$: the higher the cost of pesticide, the more the producer will rely on agronomic technique to increase yield. This might be at the cost of a lower quality.

4.2.2 Optimal strategy with residual risk

It might be that a full coverage against a harvest lower than $\overline{q}$ is not optimal. A producer might simply choose to incur the risk of selling less than the authorized harvest. In that case, contrary to the preceding one, we can not ignore the benefit part of the profit, since it varies also with the strategy. As before, we assume

$$\overline{q} < q_0$$

and we know that producers will choose $q \geq q_0$, so that the residual risk comes from the fact that sometimes the realized harvest will be smaller than $\overline{q}$. The mean of the realized sales in such a case is:

$$\text{Realized sales} = \frac{1}{2}\overline{q} + \frac{1}{2}q(1 - 2\sigma_0(1-s))$$

with a small abuse of notations, we can assimilate the realized sales, i.e. the constrained harvest, with the (modified) harvest, and denote it by q's also. Calculations in that case are much more complicated, and do not add much insights.

4.2.3 Comparison with ex-ante regulation

The preceding analysis allows us to state the following:

Proposition 3 *For the same realized sales level, ex-post regulation of quantity induces a smaller use of pesticide than ex-ante regulation.*

The logic behind this result is straightforward. Under the ex-post constraint, the producers can target any q they want, they simply do not harvest (or sell) the superfluous quantities. This allows them to incur less costs (since the constraint is such that $\overline{q} < q_0$), and in addition reduces their demand for pesticide. Of course, the quality obtained under ex-post and ex-ante restrictions are not necessarily the same.

In fact, the proposition illustrates that it is the ex-ante specification of the AOC requirement which is most responsible for pesticide use. But this is a necessary constraint from the quality point of view, and one cannot attain high quality levels without it. The trade-off is therefore rather between high quality and intense pesticide use than between quantity produced and pesticide use. This is the main specificity of the wine market. To deal with this specificity, only a specific answer can be given. This is what we undertake in the next section.

4.3 Quality vs Quantity

To introduce explicitly quality concerns in the model, we use a simplified model that replicates the technical trade-off (Giraud-Héraud et al., 2003) and the collective reputation effect (Fleckinger, 2007) pervasive in the case of French wine. We consider a compact monopoly model with the following inverse demand function:

$$p(q, \tilde{q}) = a - b\tilde{q} - \beta q$$

where β measures the quality loss imputable to quantity. Then the expected monopoly profit write:

$$\pi_M(q, \tilde{q}) = (a - b\tilde{q} - \beta q)\tilde{q} - c(q - q_0)^2 - h\tilde{q} - (w + t)sq$$

This problem displays the same features as the one studied above, and it would therefore leads to the same qualitative results.

5 Other tools and regulation issues

We have investigated here the effect of tax, book of specifications and product differentiation on the pesticide use in the French wine sector. There are a few other instruments to regulate pesticide use. We have already mentioned the ambient tax which does not seem applicable in the present context. Another instrument is quota system, thoroughly explored in other applications. In the case of wine, quotas do not seem to be a good solution because designing a satisfactory allocation appears very difficult, in view of the large heterogeneity among regions, and among different producers of the same region. In addition, even if an exchange system would theoretically lead to an optimal allocation in terms of cost efficiency, the geographic concentration of the most productive farm would probably have a strong environmental impact in those areas. While no other instruments than those exposed seem to be potentially interesting for diminishing pesticide use, refining tools may contribute to lesser the pesticide use pollution in viticulture. Among that possibilities, the most prominent ones are differentiated taxes accounting the toxicity of the pesticide, norms on application zone and subsidies for improved spraying techniques. Of course, the adoption of best practices in terms of agronomic technique should be considered a priority. All this measures should clearly be accompanied by better information and training of the farmers.

6 Conclusion

We have developed a model of pesticide regulation in the context of French wine in order to study the interplay of environmental regulation and economic regulation. The wine sector is indeed subject to professional regulation and rules set by public authorities that are likely to interact strongly with pesticide consumption control. Indeed, we find that pesticide use tends to be higher under quantity regulation. The issue in such a context is therefore to balance producers' revenue and environmental pollution of pesticide. While the introduction of a pesticide tax might be environmentally ineffective -as the non-responsiveness result for low levels of tax shows- it is likely to have a significant financial impact when influencing producers' behavior. It appears then that bundling the two kinds of regulation would a more effective way to both sustain production in the long run and limit environmental damages.

A Appendix: The social impact of risk

This section presents simple elements from the theory of commodity price stabilization (see in particular Newbery and Stiglitz, 1979, 1982; Wright and Williams, 1984) that are relevant in the present context. The market under consideration is a risky one, since the harvest are functions of the weather (or, for the case we are interested in, the disease). Is risk a case for (net) revenue insurance, or on the contrary does it benefit to some parties? It is clear that the producers are harmed by the fact that their yield is risky: their profit is concave in quantity, so they have an interest in stabilization, provided it is not too costly. On the consumers' side, this all depends on the shape of the (ex-post) inverse demand, p. Consider the realized consumer surplus:

$$CS(q) = \int p(q)dq - p(q)q$$

so that:

$$\begin{aligned} CS''(q) &= -qp''(q) - p'(q) \\ &= -p'(q)\left(1 + \frac{qp''(q)}{p'(q)}\right) \\ &\equiv -p'(q)(1 - C(q)) \end{aligned}$$

where C represents the relative curvature of the inverse demand: The higher C, the more convex it is. Since p is decreasing, the consumer surplus is convex if and only if the curvature is smaller than 1, i.e. if the demand tends to be marginally declining[6]. For example, with a linear demand, the curvature is constantly zero, so that the consumers benefit from climatic risk.

To conclude, while the social surplus is clearly concave in q, and therefore risk-reduction is socially beneficial, the preferences of producers and consumers are not necessarily aligned regarding risk managing policies.

[6]For food and beverage, this seems to be the case, at least in developed countries.

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