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## **Overcoming grape growers' pesticide lock-in**

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## Sortir du verrouillage technologique phytosanitaire en viticulture

### Résumé

*Un cadre d'analyse évolutionniste est mobilisé pour étudier la question de la réduction des pesticides en viticulture. Après avoir analysé le lock-in des viticulteurs vis-à-vis de l'utilisation des pesticides, nous montrons que, bien que l'IPM (Integrated Pest Management) permette de réduire de manière significative les quantités de pesticides employées, l'absence de compétences spécifiques dans les exploitations entrave sa diffusion. Par conséquent, une fois les caractéristiques de l'évolution technologique pour la lutte intégrée analysées, nous discutons de la réglementation environnementale comme un moyen possible de promouvoir la diffusion de l'IPM. Nous montrons toutefois que, bien qu'une telle réglementation soit nécessaire, elle est insuffisante: les viticulteurs ont également besoin de conseil et de services de vulgarisation*

**Mots-clés :** cadre évolutionniste, innovation environnementale, IPM, pesticides, viticulture

### Overcoming grape growers' pesticide lock-in

#### Abstract

*An evolutionary framework is used here to study the issue of pesticide reduction in vineyards. After analyzing grape growers' pesticide lock-in we show that, although Integrated Pest Management (IPM) could reduce pesticide use significantly, the lack of specific implementation know-how hampers its diffusion. Consequently, once the features of technological change for IPM have been scrutinized, we adopt a case analysis approach in which environmental regulation is envisaged as one possible way of promoting IPM diffusion. We also show that, however necessary such regulation is, it is insufficient: grape growers equally need extension services.*

**Keywords:** evolutionary framework, environmental innovation, IPM, pesticides, grape growing

**JEL :** Q59, O13, O33

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# 1. Introduction

The question of sustainability has now brought the environmental dimension of human activities to the fore. Agriculture, inherently concerned as it is with the natural environment, is strongly affected by society's expectations for natural resources management. Most agricultural environmental problems boil down to pesticide<sup>1</sup> use (OECD, 2001), and grape growing is no exception. Although vineyards represent only 3% of French cultivated areas, they utilize some 20% of its pesticides (Aubertot *et al.*, 2005). Consequently, grape growers are nowadays confronted with an ever-growing social demand for pesticide reduction. However, achieving any sizeable reduction is subject to several technical brakes: a permanent crop, the absence of efficient genetic or biological solutions, high stakes for quality winemaking. Yet, alternative solutions do exist to reduce the use of fungicides<sup>2</sup> in grape growing. One of these alternatives, Integrated Pest Management (IPM), allows for a significant reduction of pesticides, whilst making it possible for producers to maintain their production goals. Although IPM is used in some vineyards, it seems rather difficult for most growers to shift away from using chemical control. However, as the French government wants to obtain a 50% reduction in pesticide use by 2018 (Paillotin, 2008), it becomes urgent to study the determinants of IPM diffusion. Unfortunately, while grape growers have become increasingly aware of environmental risks, the diffusion of IPM is still rather limited.

This paper proposes analyzing pesticide reduction in grape growing thanks to an evolutionary framework, because evolutionary theory significantly enhances our understanding of technological change processes. In this field, Cowan and Gunby (1996) apply the general concept of lock-in developed by Arthur (1989) to the case of pesticide use in agriculture. The mechanisms of this pesticide lock-in have to be taken into account to analyze how to promote pesticide reduction and IPM. Our analysis of the technological change needed to escape grape growers' lock-in and to reduce pesticide use is based on a dynamic approach (Cohen and Levinthal, 1990; Dosi, 1982; Dosi *et al.*, 1988). As suggested by Possas (Possas *et al.*, 1996), we consider the innovation process at farm level, not just at upstream industry level. In this paper, we show that IPM implementation requires a combination of tacit knowledge and skills, and a new design of protection processes that generate switching costs and lower payoffs in farms. In addition, overcoming former-technology lock-in by means of innovation is known to be difficult, as chemical control benefits from firmly established routines, specialized competencies and network externalities. That is why Cowan and Gunby (1996) suggest that it would be possible to implement IPM only under certain conditions, but they do not specify which ones. In the literature, as environmental regulation is often given as an essential driver to encourage environmental innovations in firms (Oltra, 2008), we accordingly analyze the impacts of environmental regulation on IPM implementation, using a case analysis approach.

The paper is structured as follows. In Section 2, we examine growers' technological lock-in, focusing on the mechanisms used to explain the path-dependency and inflexibility bound up with pesticide use. In Section 3, not only do we confirm that IPM offers an efficient alternative to intensive pesticide use in grape growing, but we also identify its characteristics, as well as the factors responsible for the non-adoption of other environmental techniques in grape farms. We then focus on French regulation, with its potential to help overcome

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<sup>1</sup> Pesticide refers to synthetic and chemically active substances used to increase yields and to avoid damage to crops.

<sup>2</sup> Here the environmental issue mainly concerns fungicides because they represent 70% of all the pesticides used in grape growing (Eurostat, 2007).

pesticide lock-in and to promote IPM implementation (Section 4). This leads us to question whether regulation *per se* suffices to overcome grape growers' lock-in. We conclude with a brief discussion about the other potential prerequisites for IPM diffusion (Section 5).

## **2. Understanding grape growers' technological lock-in**

Many theoretical works have focused on economic processes and technological trajectories in the context of technological competition (Arthur, 1989; Cowan, 1991). This type of approach, relatively well-known at the theoretical level, has been applied to studying pesticide use in grape growing (Cowan and Gunby, 1996). Initially, the value of adopting pesticides increased, as more and more growers started adopting this process. It finally resulted, as the use of pesticides became widespread, in path-dependency and inflexibility, thereby ushering in the pesticide era, with growers becoming locked into this technology.

### **2.1. The advent of pesticides in crop protection**

The need to increase agricultural production after World War II favoured the development of several technologies to control parasites and, with synthetic pesticides first starting to appear on the market, this meant that chemical control was being introduced for grapes and other crops. Chemical control consists in applying pesticides to destroy weeds, pests and fungal diseases to avoid damage to crops. As the dates and doses of chemical treatments are generally fixed at the beginning of the year, the whole protection process tends to proceed somewhat automatically. Initially, the result of the competition between earlier techniques and chemical protection was uncertain and unpredictable, until one of the technologies finally became dominant. The advent of pesticides resulted from the conjunction of several factors, such as the immediate effectiveness of pesticides, their easy use and their relative cheapness. These characteristics led to the successful installation of the use of chemicals. Pesticides allowed damage caused by pests and diseases to be reduced significantly, thereby increasing yields and securing farmers' income, without the need for more labour. Pesticides were seen as a good, simple strategy to protect vineyards.

Secondly, within the context of agricultural modernization, certain actors helped to disseminate the idea that pesticides constituted the best available technology. Both public institutions and the chemical industry provided strong incentives for growers to switch to pesticides, with agricultural policies being built around pesticide use and the new production goals that pesticides allowed. Higher yields have thus been the constant focus of post-war public policies. In addition, as the technological opportunity provided by pesticides proved to be synonymous with huge profits, the chemical industry invested heavily in R&D programmes to develop new active substances. Chemical control quickly established itself as the best solution for protecting vineyards. Pesticides drew ahead from competition with other technologies thanks to technological and institutional co-evolution, as explained by Unruh (2000) with regard to fossil fuel-based energy systems. The cultural and biological techniques formerly used for crop protection were completely abandoned and replaced by pesticides, which became growers' favourite means of crop protection, and the dominant technology on the market. As a result, growers became as specialized as extension services in the chemical protection of vineyards.

Growers started developing chemical routines in their crop protection strategies. They decided to protect their vineyards on the basis of simple, recurring decision rules founded exclusively on pesticide use. Firms' decision rules are described, in Nelson and Winter's theory of the firm, as a set of constant provisions and strategic heuristics that shape the

approach firms have regarding the problems they face (Nelson and Winter, 1982). Routines, when applied to crop protection, can be defined as a set of operating rules and known solutions for any plant problems that may arise. Such routines, which reflect the knowledge, skills and experience of growers acquired over many years, are used daily in farm activities to manage epidemics and pests. These routines mainly consist in seamless chemical treatments to ensure that the vine is continuously protected during the period of potential contamination, whatever the risk. These practices are well-known and controlled, and give rise to systematic chemical treatments. Efforts in the 60s to increase productivity and autonomy thus resulted in growers developing very specific skills in chemical treatments. The result of such specialization has led to a knowledge base focused solely on the use of synthetic chemicals to solve vineyard protection problems.

Grape production systems became strongly dependent on pesticides and on the choices made after World War II, despite their negative impact on the environment. Ever since then, grape growers have had to face crop protection technological lock-in.

## ***2.2. Pesticide lock-in due to increasing returns, uncertainty reduction and network externalities***

Theoretical works on competing technologies offer different insights about the process that leads to a lock-in, and help us to understand why the grape growers are locked into using pesticides. The first point is that the advantage of adopting any one technology increases with the number of adopters (Arthur, 1989), thanks to increasing returns. So, the technology is improved and the benefits of adopting it increase. At farm level, pesticide use was improved thanks to 'learning by doing' or 'by using', and the practice became more and more attractive for those farmers who had not yet adopted this technology. The more farmers used pesticides, the more they gained in experience, and the more their use of those pesticides improved. Thanks to such increasing returns, this technology was chosen more and more frequently, which may well have hindered the diffusion of some other, possibly superior, technology. As pesticide diffusion proved to be a self-reinforcing mechanism, pesticides advanced quickly along their learning curve. At the same time, it is clear that, as the earlier crop protection practices gradually fell out of use, they were doomed to be forgotten. Learning experiences replaced previous techniques, thereby improving the general knowledge base about pesticides and their use in vineyard protection. This specialization in pesticide use contributed to imposing the idea that there were no satisfactory alternatives to chemical protection. So, it became increasingly difficult and costly to shift to another technology. Pesticides were also subject to increasing returns in the chemical industry, where the learning effects of new active substances could be observed in Research and Development (R&D) from a dynamic point of view. Equally, but from a more static point of view, the chemical industry benefited from economies of scale in pesticide manufacture (Cowan and Gunby, 1996). Increasing returns were, consequently, an important driving force behind pesticide lock-in.

Secondly, another factor influencing competition between technologies is the reduction of uncertainty for the firm (Cowan, 1991). The more pesticides were adopted by farmers, the more they – and their crop-protection merits – became widely-known. So farmers quickly found out how good this technology was at solving their pest problems, feeling that it was superior to what they believed former or new, alternative technologies were able to achieve. At the same time, beliefs about other technologies and techniques did not evolve. They were under-developed by firms in their R&D programmes, and no longer the subject of experimentations by professional organizations and extension services. Accordingly, all these older practices were used less and less by farmers, whilst pesticides tended to show their

superiority more and more, confirming farmers in their belief that pesticides offered the best form of vineyard protection. From the point of view of users and advisors, a technique they all knew very well meant that uncertainty was definitely reduced, even if was not completely eliminated.

As for the third driving force behind lock-in, it is bound up with co-ordination and network externalities between firms (Rosenberg, 1982). Nowadays, as almost all growers use pesticides, this amounts to a vast network. The benefit of using pesticides increases with the number of users and this, in turn, increases with the number of farmers in the network. They all benefit from the experience and knowledge of other growers, from technical co-ordination and from the development of extension services. They have no incentive to leave this large network in order to adopt some other technology, without first knowing if they would be the only ones to do so. It is not in their interest to take the risk of joining or starting a small network. They would not have the same advantages as in the previous one, and would have to support potential switching costs on their own, or else accept lower payoffs at the time of change.

Thus, the evolutionary process of plant protection practices depending on the path taken since the 60s has led to a lock-in situation, as defined in Arthur (1989), one in which the dominant technology is used by the entire population concerned. This lock-in situation developed thanks to several factors - increasing returns in pesticide adoption, 'learning by doing' effects, uncertainty reduction and network externalities - and has since given rise to the current chemical paradigm in crop protection.

### **2.3. The current pesticide paradigm**

Pesticides are still generally considered as the main way of ensuring grape protection. This problem solving model constitutes a *pesticide paradigm* (Saint-Ges and Belis-Bergouignan, 2009), by analogy with the concept of technological paradigm defined by Dosi (1982). This model allows us to make clear that growers exclusively use synthetic chemicals for protecting vineyards. This being the case, any technological progress is, accordingly, seen exclusively within the technoeconomic paradigm of pesticides. Any eventual vineyard-protection technological developments are limited by winemakers' existing knowledge base and skills. Farms follow technological trajectories<sup>3</sup> in a cumulative process, one in which their present actions depend on the actions and skills developed in the past. Technological change is the product of a previous process and depends on the know-how, knowledge and technological skills acquired by the vine growers in the past. This means that the evolution of growers' practices corresponds to technological trajectories embedded in the *pesticide paradigm*. As upstream industry firms have themselves also focused their R&D process on chemical control, their own new practices greatly depend on previously selected ones. This paradigm constrains technological change, giving it just one direction, based on the specificity of the knowledge base developed since the post-war period by farms and firms. That is why this paradigm and these chemical practices have prevailed ever since.

At the present time, pesticide innovations are somewhat far and few between. It is clear that upstream industry firms have played a major role in the development of the current technological paradigm. But it seems that, nowadays, technological opportunities for developing new active substances are somewhat rare. The potential discovery of new active

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<sup>3</sup> A technological trajectory represents the direction of problem solving (progress) in the context of a technological paradigm (see Dosi, 1988).

substances is not infinite, and the emergence of different forms of pesticide-resistance may reduce the value of existing chemical products in the future. The context of increasing product registration regulation, which tends to augment the duration and cost of development<sup>4</sup>, offers little incentive for chemical firms to innovate. So no technological breakthrough seems likely in the immediate future, even if firms improve their active substances and products. Consequently, growers continue to make intensive use of pesticides - despite their notorious impact on the environment - in order to protect their vineyards.

The above-mentioned concepts of paradigm and technological trajectory are commonly employed in evolutionary literature, which has often been used to study technological change in industry. But little attention has been paid within this framework to the processes of environmental innovation and path-dependency in farms. Indeed, since the agricultural sector is described by Pavitt (1984) as being 'supplier dominated', any analysis of innovation in this sector has accordingly been centered on the study of innovation in upstream industries (Possas *et al.*, 1996). Innovations are only considered to be incorporated into farms' production processes via their suppliers. Alternative sources of innovation and the complexity of the innovation process are actually ignored, because lock-in affects the entire system. In the current situation, in which it is necessary to switch to a new standard, we argue that analyzing the innovation process at farm level is essential, because no new supply side technological solution is available to replace pesticides. This lack of alternatives offered by suppliers does not mean that there is no solution for escaping lock-in. The current need is to consider innovation processes at farm level, because that is where pesticide-reduction alternatives seem to be emerging.

Grape farms are embedded in a pesticide lock-in. This situation results from a process of technological and institutional evolution driven by path-dependent increasing returns. Although technological opportunities for pesticide reduction do exist, replacing an existing technology by another one is by no means automatic. Reversing lock-in is a long-term struggle.

### **3. IPM: an alternative pesticide-reduction strategy waiting to be adopted**

To improve their environmental performance, farmers must change their approach to vineyard-protection problem solving. This means that they have to find new technologies and to implement one or more environmental innovations in their production processes. At the present time, IPM is considered as the major alternative strategy to chemical control in grape growing, but several brakes stop its being adopted on a large scale.

#### **3.1. IPM is a new disease control strategy in grape growing**

Given the severity of pollution from pesticides and the emergence of resistance to these products, FAO<sup>5</sup> convened in 1967 a committee of experts to develop the concept of IPM<sup>6</sup> (IOBC, 1993). IPM is often used to control pest damage to crops by means of biological

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<sup>4</sup> The development of a new active substance represents about 10 years of research and 200 million euros according to the Union of French Plant Protection Firms.

<sup>5</sup> FAO: Food and Agricultural Organization.

<sup>6</sup> In grape growing, IPM is defined as an economically viable protection process for high quality grapes, giving priority to environmentally-friendly practices, minimizing the unintended and undesirable effects, whilst minimizing the use of pesticides to safeguard the environment and human health (IOBC, 1993).

methods. Although IPM is designed to encourage the use of alternatives to chemical control, it is, nonetheless, possible to use them in conjunction with pesticides. The primary aim of IPM is to ensure that the expected yield is obtained, while minimizing negative effects on the environment. As the focus is more on potential economic - rather than physical - damage, this constitutes a new way of considering protection process results. Pesticide use is reduced, whilst standard production objectives – the quantity and quality of grapes – are maintained. As far as possible, no chemicals are used, but when there is no other solution, pesticides are allowed under specific conditions. This means that farmers use pesticides differently, thereby changing the way they organize their crop protection practices. The implementation of this concept in farms results in environmental process innovations<sup>7</sup> that modify the whole range of farmers' technical practices, including chemical ones. New technologies and new technical operations introduce new technical chains, which means that decision rules have to change as well.

If we take the example of fungicides in grape growing, the introduction of IPM is relatively recent. This alternative has been profitably applied to many crops for a long time; on occasions, even, it has been used in grape growing to deal with insects. But the main problem faced by grape growers is the use of fungicides, for which there is still no agronomically or organically efficient alternative. In recent years, however, a new decision process - developed by the French National Institute for Agronomic Research (INRA) - allows fungicide use to be reduced by 40%-70% in the case of powdery and downy mildew (Cartolaro *et al.*, 2007). This new decision process involves, *inter alia*, such new vineyard-protection practices as joint management of both diseases, as well as effective vineyard disease-specific monitoring at three key stages. The information collected during these observations is confronted with other data (the climate and prevalence of specific diseases in the area) to decide whether chemical treatment is necessary or not. So, IPM requires new competences to first observe the vineyards, confront the data and then take the right decision. Metcalfe (1995) describes technology as the result of a combination of skills, knowledge, artefacts and organization necessary for the production of new technological artifacts. IPM is here, too, the result of a complex process, a confrontation of data, thanks to specialized knowledge and skills leading to a new protection process in vineyards.

Fernandez-Cornejo (1998) presents the characteristics of those grape farms that have adopted IPM in the United States. He shows that the implementation of these practices is positively correlated with the availability of the operator (time of 'labor'), farm size and the grower's level of education. On the contrary, farmers' experience seems to have a negative impact on the probability of adopting IPM, which shows that older growers tend to be more reluctant to adopt new technologies. This is also true in what concerns different types of grape: IPM is more often used in table grape farms than in wine farms, with the advice provided by the extension services seemingly having no effect on the adoption of IPM. This author shows that the adoption of IPM leads to significant fungicide reduction and lower insecticide toxicity. A whole range of factors, such as pesticide prices, grape prices and infestation levels, seem to be involved in farmers' decisions to adopt IPM. It should be noted that yields and profits are higher in all farms using IPM, whatever their crops<sup>8</sup> are. Although the study led to an interesting characterization of farms having already adopted environmental practices in different sectors, it fails to help us understand the mechanisms involved in IPM

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<sup>7</sup> We consider an environmental process innovation as the production, assimilation or exploitation of a production process that is novel to the firm, and which results in a reduction of the environmental risk, pollution and other negative impacts of resources use compared to relevant alternatives (cf. MEI Report, 2008).

<sup>8</sup> See Hall (1977), Cowan and Gunby (1996) for studies about IPM concerning citrus and cotton, for example.

diffusion. In addition, few European farms have chosen to implement IPM, and there are very few signs indicating that its adoption rate is likely to change. The implementation of IPM techniques seems to be rather long, difficult and dependent on the context, reflecting the slow progression of these practices during the 40 years the FAO has enunciated the principle. Attention, therefore, should be focused on the brakes, as well as on the determinants, involved in the diffusion of such practices in grape growing.

Although IPM seems to allow a combination of environmental and economic performances, the lock-in situation - and the technological change characteristics involved - all tend to make this difficult.

### **3.2. A knowledge-intensive, highly uncertain and specific process of technological change**

The difficulties growers have in implementing IPM can be declined around three of its major characteristics. This technology is particularly knowledge-intensive and requires management skills to modify routines, especially as regards the decision to spray or not. The use of pesticides is replaced by the knowledge and skills required to manage vineyard protection with limited chemical input, to monitor diseases, and to acquire and process climate data. So, reducing pesticide use necessitates a complex learning process in order to develop these new skills. This means that the whole technical chain must be modified and that farmers have to change their vineyard protection routines. However, being knowledge-intensive initially implies high fixed costs, because the issue of vineyard protection is a complex one. Epidemiology is not well-known by grape growers because theirs is a permanent crop. Early identification of fungi diseases is relatively new for the growers, who need to acquire human capital to control monitoring techniques and to master the new decision rules for spraying only when necessary. It is also essential to carefully define the appropriate spatial units for decision rules and treatments. Once the whole process has been launched, 'learning by using' reduces average costs because less input is needed to produce grapes, and decision rules become easier to apply. In fact, human capital is an essential input in IPM for monitoring crops and observing diseases (Aubertot *et al.*, 2005). This monitoring can be ensured by the farmers themselves, or by public or private extension services. The cost of this activity would be lower if it could be shared between many farmers when there is high demand in a specific area. Concentrated vineyards, such as those in Bordeaux, Languedoc-Roussillon and Burgundy, could easily arrange to pool this service. But extension services and growers alike have also to change their practices and knowledge base to support the technological change needed in grape farms.

Another feature of IPM is the uncertainty that comes with the adoption of a new technology. This uncertainty, in fact, prevents IPM from replacing pesticide use or from having a stronger position on the market. In the evolutionary literature, Dosi (1988) describes the uncertainty inherent in the innovation process as very high, since the technoeconomic consequences<sup>9</sup> of events are not known; this all adds to the environmental uncertainty that characterizes environmental innovations (Saint-Jean, 2002). Arundel and Kemp (2009) have also identified the lack of information about the impact of changing the overall economic equilibrium of firms as being an impediment when modifying practices and integrating

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<sup>9</sup> Firms need both technical and economic information about alternatives, since the potential environmental benefit of environmental innovations is not sufficient to induce firms to implement them. Their adoption is, in fact, largely based on the occurrence of a "double win" outcome coupling environmental and economic gains (Porter and van der Linde, 1995).

environmental stakes. Having no information about the impact of a technical modification is, therefore, an important reason behind growers' reticence to change their practices (Saint-Ges and Belis-Bergouignan, 2009). It is certainly a fact that growers cannot identify all the alternatives available, and often do not even know anything about IPM or its implementation. This means that they are totally unable to envisage the eventual profits to be made from IPM implementation. So, faced with the impending need to reduce pesticide use, growers feel uncertain because IPM is, for them, an essentially unknown process of protection which, they believe, is not easy to control. They lack the necessary on-farm experience to convince them of its effectiveness, and they are not sure that IPM really works. They have no such doubt about intensive pesticide use, since they feel perfectly capable of anticipating all the costs and technical results. The doubts they have are further compounded by the fact that IPM implies acquiring skills to change their routines and to modify their production process.

A third factor has to be taken into account in addition to knowledge intensity and uncertainty: the heterogeneity of the protection practices in vineyards. Among the trajectories of grape farms, there is generally significant heterogeneity in the crop protection practices implemented. As an example, conventional strategies chemical practices can contain from 7 to 22 treatments in French vineyards (SCEES, 2006). Unfortunately, however, the sheer diversity of these practices is not taken into account in the literature (Blazy and Ozier-Lafontaine, 2009), even though the winemakers' decision rules are based on specific thresholds: those of satisfaction, production goals and past experiences. Rosenberg (1982) and Dosi *et al.* (1988) note that firms differ, likewise, in their ability to accumulate experience. We argue that grape farms differ in the technical and organizational structures formalized in their routines, as well as in their skills and ability to collect new information and to acquire new competences. All of this implies specific types of behaviour and performance associated with each farm, especially since similar practices can lead to different results. Consequently, the results in adopting IPM should be different in every farm, thereby reinforcing the feeling of uncertainty linked to IPM. It is not a simple recipe in which protection practices can be merely copied from one farm to another. Heterogeneity characterizes the wine sector, with each farm following its own path. As no standard farm is to be found, it cannot therefore be the subject of analysis.

These characteristics of IPM implementation constitute major brakes for its adoption on a large scale. That is why some authors argue that IPM implementation is impossible - unless crops face severe decreasing returns caused by pest resistance, and no other solution can be found. Most empirical observations confirm that farmers then shift away from chemical control, despite their lack of prior experience using IPM (Cowan and Gunby, 1996). Although grape growers are not currently confronted with such resistance they do, nonetheless, have to deal with official French regulation.

Even though pesticide lock-in is omnipresent, it is still possible to envisage IPM providing an environmental innovation for pesticide reduction. This would lead to potential win-win paths in grape growing. Unfortunately, however, IPM has not taken hold on a large scale, and its characteristics - knowledge intensity, uncertainty and specificity - do not encourage its widespread adoption.

## **4. The potential role of environmental regulation in IPM diffusion**

Given the importance of the social demand for environmental preservation, French regulation can play a role in overcoming the brakes for IPM implementation in grape growing. French pesticide reduction regulation tries to encourage the adoption of better environmental practices, fixing the objective of reducing pesticide use by 50% by 2018. We therefore examine regulation as a potential driver for overcoming learning problems, allowing IPM to emerge and then predominate in vineyards.

### **4.1. Regulation as an important determinant for environmental innovations and their diffusion**

Regulation is traditionally considered in environmental economics literature as a driver to control and encourage environmental practices. Environmental innovations are often described as being induced by regulation and its ensuing pressure. Regulation should play an essential role, since environmental innovations cause what is called a “double externality” problem. Environmental innovations produce two types of positive externalities. First, they produce knowledge externalities as do other innovations in the research and innovation phases. They also produce externalities, thanks to their positive impact on the environment, which always makes them socially desirable. Firms have low incentives to innovate for environmental preservation because the social wellbeing generated from environmental practices primarily favours the general public, thereby hindering private incentives. Regulation is, consequently, considered as an important tool to give firms incentives to innovate, particularly in what concerns process innovations (Cleff and Rennings, 2000). Regulation's double effect on environmental innovations is what Rennings (2000) calls the regulatory push/pull effect:

- First, regulation shows firms the direction needed to improve their technological practices and how to improve production processes and products. It drives technological change, forcing firms to follow new paths. In the case of grape growing, the role of environmental regulation can be illustrated by the regulation about point-source pollution and end-of-pipe<sup>10</sup> innovations in France. The aim of the existing regulation in grape growing is to reduce point-source pollution, thanks to the emission of norms about management of effluents, local construction to stock chemical products, limitation of use for hazardous products, strict approval of new active substances, and so on. Significant reductions in point-source pollutions have thus been observed during the last few years in France, thanks to environmental policy.
- Secondly, regulation participates in the creation of environmental preservation demand by alerting people about the environmental impact of activities or products. Regulation has increased the demand side of environmental preservation, resulting in an increase in the societal pressure being exerted on agriculture, pressure that had, for the most part, previously been ignored. Consequently, thanks to public policies and national meetings, the environmental awareness of French society has grown.

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<sup>10</sup> Frondel *et al.* (2007) show more generally that end-of-pipe technologies are still dominant in many OECD countries and that, in these countries, environmental regulation tends to promote the use of such technologies.

The focus of empirical studies mainly concerns the evaluation of which policy instrument creates the highest incentive for firms to innovate, rather than on understanding the innovation process itself. Their results tend to confirm the Porter hypothesis, which affirms that relevant and well-designed environmental standards can trigger innovation, something which may well offset the costs of complying with such standards (Porter and van der Linde, 1995). Consequently, many authors argue that regulation is a key factor in influencing the innovation process of firms. But there are still controversies about the effective impact of regulation, and also about the most efficient tool for giving incentives to firms. Further studies focus on other evolutionary determinants of environmental innovations at demand and supply sides in evolutionary literature. In spite of the incentive role of regulation, environmental innovations cannot be considered as a systematic response to regulation. Other factors, linked to market conditions and to the technological capabilities of firms, may determine the technological response of regulated firms (Oltra, 2008). Currently, many studies focus on consumer demand and its role in the adoption and diffusion of environmental innovations (Taylor *et al.*, 2006). But Rennings (2000) shows that consumers' willingness to pay is rather low for environmental improvements. This tends to be confirmed in the case of environmentally-friendly wines (Bazoche *et al.*, 2007).

#### **4.2. Regulation: necessary, but not sufficient by itself, to overcome the brakes for IPM diffusion in grape growing**

Until 2008, grape growers had almost no incentive to adopt IPM in an uncoordinated market because, in that case, the market under-supplied IPM adoption and switching costs. In year 2008, the new French pesticide reduction regulation starts by establishing the objective of reducing pesticides by 50% in 2018. One advantage of the Paillotin report is that it essentially shows the direction of technological change, suggesting some guidelines for experimenting and monitoring such new protection practices as IPM or organic farming in France (Paillotin, 2008). However, concerning the implementation of pesticide reduction, recommendations are only based on the voluntary behaviour of growers without, however, specifying any tools to implement it. But many regulatory tools can be used to promote the technological change needed for pesticide reduction. Firstly, it seems that even if not all farms manage to comply with agricultural and environmental policies (Saint-Ges and Belis-Bergouignan, 2009), the introduction of norms can improve the environmental impact of wine growing. However, concerning the reduction of diffuse pollution and pesticide use, the emission of norms and standards is somewhat compromised compared to other sectors. Indeed, it is difficult to envisage the comprehensive control of all farms because they are numerous, very scattered throughout the territory, and also because it is practically impossible to determine which farmer caused diffuse pollution. Taxes are also often cited in the literature as a relevant tool in agriculture for limiting pesticide use. Although there are few empirical studies on this topic we can, however, observe that the recent high increase in the price of some chemical inputs did not result in a significant decrease in their use<sup>11</sup> (Eurostat, 2007). This means that, without a strong political will, grape growers will tend to continue using the best-known technology: chemical control.

There is a need to focus on the reasons why IPM is not currently implemented on a large scale. In fact, reducing uncertainty, and providing growers with the specific knowledge they need to implement IPM, are both crucial if growers are to change their protection

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<sup>11</sup> The slight decrease in pesticide use to be found in recent years is essentially due to the withdrawal of many active substances, as well as to the marketing of new active substances that are efficient at lower quantities.

practices. As long as growers are in a state of uncertainty, and are not reassured about the technoeconomic efficiency of this protection process, they will have no incentive to develop IPM. Regulation can play a role in this domain, thanks to guidelines concerning the promotion of private and public research to accumulate technical, environmental and economic data about new protection practices. Elsewhere, the Paillotin report envisages creating a large network of various farms having already implemented IPM, in order to acquire references. Even if such farms are not numerous in France, once a certain volume of IPM information and knowledge implementation has been generated, this will then be available for all grape growers, thereby reducing the lack of information that currently contributes to grape growers' uncertainty.

There still remains, unfortunately, the second point, i.e. grape growers' learning process. Grape growers have to develop, in particular, the new knowledge and skills they need for monitoring vineyards and for developing the decision rules to trigger a chemical treatment or not. Consequently, such knowledge intensity requires the development of a new knowledge-base regulation. Grape growers cannot implement internal R&D processes on their own, and have to search for new solutions to develop their knowledge and competencies. All this would require new models for the generation, evaluation and dissemination of knowledge, but regulation gives no specific direction on this point. Grape growers' learning process is very important, because it is linked to the issue of the increasing returns that can be obtained if knowledge about IPM can be disseminated in grape farms. The more grape growers monitor their vineyards and acquire data, the more reason other growers will have to adopt IPM. Consequently, 'learning by using' effects will allow grape growers to advance quickly on their learning curve, not only thanks to individual learning, but also because each individual experience will enhance the collective knowledge base. In addition, the average protection cost will drop with a rise in the number of users; this is an important point concerning payoffs when IPM implementation is first launched. Thus, benefits from IPM use will increase with each new user. So, existing networks with neighbouring grape farms and local organisations will certainly have an important role to play in the diffusion of IPM. But, the current regulation gives no incentive for local learning and for encouraging network externalities. So, French pesticide reduction regulation cannot solve the learning problems the producers face. Based on the characteristics we have highlighted for IPM, we argue that this new environmental regulation certainly shows the direction of the necessary change but that, for several reasons, this definitely does not suffice to promote new protection practices like IPM. That is why, in addition to environmental regulation, it will be important to explore and analyze the mechanisms involved in grape growers' learning process.

The literature and empirical examples show that environmental regulation can be a strong driver for environmental innovations in firms. But, if regulation shows the direction of the technological change and participates in reducing grape growers' uncertainty, it is not a solution for developing new models for the generation and diffusion of knowledge. So we can anticipate that the current Ecophyto 2018 plan will not be sufficient to achieve the objective of a 50% reduction in pesticide use by 2018.

## 5. Concluding remarks

The challenge of grape growing for the coming years is to significantly reduce pesticide use in vineyards. But grape growers are embedded in pesticide lock-in. So pesticide reduction involves a technological change in protection practices, moving away from chemical control to more environmental techniques like IPM. The purpose of the paper has been to show the benefits of using an evolutionary framework to understand the technological change linked to pesticide reduction in grape growing. In this context, the paper explains (i) the main reasons for farmers being locked in to pesticides. The evolutionary approach highlights the lock-in situation, and the mechanisms that have led to this situation. The paper also shows (ii) that although IPM is an alternative strategy for wine protection, there are brakes that hamper its diffusion and (iii) that environmental regulation is necessary but not sufficient to impulse the technological change. Environmental regulation is certainly useful to prod farmers into taking the right technological change direction needed to reduce pesticide use. But it cannot be efficient *per se*, because IPM characteristics inhibit its diffusion. It seems that IPM diffusion requires, firstly, a strong political will that includes farm incentives and promoting the direction of public research. Regulation has to ensure that farmers reduce their pesticide use in the coming years. Secondly, technological opportunities like IPM need technical and economic information coming from on-farm experiences to validate IPM efficiency. Lastly, in order to implement IPM in their farms, grape growers have to start learning processes, in order to acquire the necessary knowledge and competences. IPM is a highly knowledge-intensive technology. Its application remains uncertain for grape growers, whose learning process is, finally, a key point in any innovation process including IPM implementation ; this, is in addition to regulation. So, further research must now focus on the identification and understanding of the mechanisms that govern learning models in grape growing.

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