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Abstract

This article explores the economic conditions for the viability of organic farming in a context of imperfect competition. While most research dealing with this issue has adopted an empirical approach, we propose a theoretical foundation. Farmers have a choice between two technologies, the conventional one using two complementary inputs, chemicals and seeds, and the organic one only requiring organic seeds. The upstream markets are oligopolistic and the firms adopt Cournot behavior. The game is solved backward. The equilibrium repartition of the farmers between both sectors is obtained by a free entry condition.Since multiple equilibria could exist, including the non emergence of organic farming, we spell out viability conditions for organic farming. Then, using an "infant industry" argument, we propose several public policy instruments able to support the development of organic farming, and assess their relative efficiency. Results could be usefull to asses the conditions of emergence and viability of agricultural innovations in analogous contexts.

Keywords: agricultural inputs, organic farming, imperfect competition, technological choice, free entry, policy design
JEL Classification: Q12 , L13

1 Introduction

Organic agriculture is defined by the International Federation of Organic Agriculture Movements (IFOAM) as "a production system that sustains the health of soils, ecosystems and people".

> *"It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved".*

Thus, the ambition of organic farming is to accommodate agricultural production and the consumers' interest, by limiting the impact of agriculture on the environment. While some experts express doubt about the efficiency of organic farming, several studies show sustained interest and willingness of consumers to pay for organic products (Boccaletti and Nardella, 2000, Dimitri and Richman, 2000, Batte et al., 2007). That paradox makes the study of the conditions of emergence of organic farming a real challenge for research (Park and Lohr, 1996) . Most research dealing with this subject adopts an empirical approach, and focus mainly on farmers and farms characteristics (Burton et al.,2003, Wheeler, 2008, Wynen and Edwards, 1990). Very little research has been performed on the type of policy instruments able to enhance this emergence (Dimitri and Oberholtzer, 2005, Eerola and Huhtala, 2008).

Of course, farms characteristics matter. Considering Kleffer et al. (1977), Oude Lansink et al. (2002), Offerman and Nieberg (2000), Mayen et al. (2010), we must conclude that the organic sector is less productive than the conventional one. As a consequence, the emergence of an organic sector is only possible if the price of the organic products are not too close to the conventional one and/or if there is some mechanism that compensates this productivity gap (Mayen et al., 2010). This is why we incorporate two basic features that are often associated to organic farming: A "*learning-by-doing*" process and the existence of a "*niche market*" for the corresponding products.

The first feature is borrowed from Hanson et al. (1997), Martini et al. (2004) and Sipiläinen and Oude Lansink (2005). It relies on the idea that the adoption of organic production requires specific knowledge or at least some early experiments performed by innovators. Sipiläinen and Oude Lansink (2005) estimate technical efficiency of organic farming and its development over time in Finnish dairy farms. They conclude that "*the average efficiency at first decreases* (when the conversion towards organic farming starts) *but at a decreasing rate, and turns then after* 6-7 *years to an increase*" suggesting "*learning effects related to the experience in organic farming*".

It is well documented that some consumers are willing to pay more for organic food (Batte et al., 2007, Krystallis and Chryssohoidis, 2005, Yiridoe et al., 2005, Boccaletti and Nardella, 2000, Gil et al., 2000, ...). It is therefore quite obvious that organic farmers do not produce, say, for a worldwide market but address more local markets in which they meet specific consumers with a higher willingness to pay. But unfortunately, and contrary to the learning effect, this additional profit opportunity decreases with the number of organic farmers because the quantity supplied to this "niche" market simply increases.

However, farming decisions are not only based on farm constraints and farmers' preferences (Jaeck and Lifran, 2009) but rely also on the characteristics of the marketing channels in which the farm is involved. That encompasses the set of relationships with both upstream and downstream firms. This literature underlines the oligopolistic and oligopsonistic structure of industrial food market, the implications in terms of price transmission along the marketing channel and the profit capture realized by the upstream firms (see for instance McCorriston et al., 1998, Rogers and Sexton, 1994, Saitone, Sexton and Sexton, 2008, Weldegebriel, 2004).

In this paper we focus on the behavior of upstream the input providers who are usually recognized as acting as an oligopoly (Fulton and Giannakas, 2001, Hayenga, 1998). This peculiar market structure is induced by the strategic behavior of upstream firms, and their interest in merging or in vertical integration (Fulton and Giannakas, 2001, Johnson and Melkonyan, 2003, Shi, 2009). Moreover, Just and Hueth (1993) show that the joint supply of complementary goods by a unique firm will be larger than the one proposed when each of the two goods are supplied separately. That arises because of the increasing cross marginal revenue.

This is why we assume that the agricultural inputs suppliers propose seeds and chemicals simultaneously to all farmers. As a consequence, they have a great influence on the adoption of the technological package by the farmer. To be more precise, we present a model in which the two agricultural inputs: seeds and chemicals, are complementary, and are jointly sold by upstream firms. For the conventional sector, firms supply the two goods as a "bundle", as presented by Shi and Chavas (2008), and Shi (2009), while, for the organic sector, they provide only specific seeds without chemicals.

Given this particular context of imperfect competition, our paper attempts to characterize the conditions of emergence and viability of organic farming. We propose a three step game. In the *first step* the farmers choose their mode of production by implementing either organic or conventional farming. This choice is based on the comparison of the expected return of each technology and by the potential learning by doing effect. Moreover, since there is free entry in each sector, an equilibrium distribution is reached as soon as no farmer wants to change his mode of production. The equilibrium that occurs at this stage provides some insights on the condition of the emergence of organic farming. In the *second step*, the input providers choose the amount of chemical-free seeds and quantity of the bundle of seeds and chemical they want to sell on these two input markets. The transactions on this two markets result from a Cournot equilibrium in which these downstream firms take into account the profit they can capture from both sectors. Finally, in *step three*, farming takes place and the products are sold either on a "niche" market for organic farmers or at the current worldwide price for conventional farming. Since we seek a Nash equilibrium we solve this game backwards.

By solving this game, we also gain more insights on the conditions of the emergence and the development of the new technology. This is why we also analyse the set of instruments a policy maker would implement to boost the emergence of organic farming. Supporting for organic farming emergence could arise from an argument that it is an "infant industry" to be protected from rent capture by upstream oligopoly trough their power market. Competition enhancing policy could also be invoked and social welfare enhancing arguments could legitimate the support of "environnemental friendly technologies" (Eerola and Huhtala, 2008). However, imperfect competition places specific constraints on the design of the instruments. We will assume that the regulator cannot significantly control the degree of competition among the upstream firms, and that he will contemplate only "conventional" instruments : a tax on chemicals, subsidies to organic seeds, subsidies to the production of organic products and actions to speed up the learning process about the new technology.

As the imperfect competition context appears to be widespread in the agricultural sector, the conclusions of our study about the emergence of organic farming could be relevant for all situations where a new technology and the corresponding market compete with the conventional one.

The paper is organized as follows. In section 2, we present the model, its assumptions and solve the three step game. Section 3 is devoted to the study of quantity flows, i.e. the production of the farmers and the equilibrium level of inputs, for a given distribution of the farmers between both sectors. In section 4, we study the condition of the emergence of organic farming by studying the properties of our free entry equilibrium. Section 5 addresses some public policy issues (subsidies for organic farmers, taxes on chemicals etc.) and their role in easing or blocking the emergence of organic farming. Section 6 contains concluding remarks. Proofs which are not central to the argument are relegated to an appendix.

2 The model

Consider an economy in which the agricultural sector is composed of two types of farmers. The first type, called conventional, produces a generic product dedicated to a large market. The second, called organic, produces a specific chemical-free product and targets a niche market. Both buy seeds or a bundle of seeds and chemicals from a small number m of upstream firms which exert some market power. Within this structure, each farmer (within the total number N) will choose either classical or organic farming. We denote by n the number of organic farmers.

Within the *conventional sector*, seeds and chemicals are complementary inputs. From that point of view, we assume that the upstream firm typically sells, at price p_b, a bundle in which there is a fixed proportion of chemicals to seeds. Hayenga (1998) presents a linked seed and chemicals market, and concludes that the strategy of input providers is "*to tie the seed customer more closely to the chemical product*". We also assume that the quantity of land is given, and that the farmer allocates all his working time to the agricultural activity. He is not constrained by water availability or others inputs. We can therefore reduce the production function to a unique input: the amount of conventional seeds s_c. We denote this function by $f(s_c)$ and assume as usual that this function is increasing and exhibits decreasing return to scale, i.e. $f'(s) > 0$ and $f"(s) < 0$, satisfies the Inada conditions, i.e. $\lim_{s\to 0} f'(s) = +\infty$, $\lim_{s\to +\infty} f'(s) = 0$ and does not allow "free lunch", i.e. $f(0) = 0$. We also introduce two additional assumptions: the elasticity $e_{f'}(s)$ of f' remains bounded, the elasticity $e_{f"}(s)$ of $f"$ is larger than -2[1].

We finally state that the output of the conventional sector is sold on a large, competitive and perhaps worldwide market, at a given price p_c. This simplifying assumption gives us the opportunity to treat the conventional farmers as pure competitive players and to mainly focus on the interaction with their suppliers.

The *organic sector*, by contrast, does not use chemicals and uses chemical-free seeds at price p_s. We again assume that the production function of this sector depends only on the amount of seeds used s_o. This production function is quite the same as the one for the conventional sector, in the sense that, without chemicals, the marginal productivity is reduced by some factor $\beta \in [0, 1]$, and is given by $\beta f(s_o)$. Consistent with Rouvière and Soubeyran (2011), the emergence

[1] In our vertical structure the demand of inputs is linked to the marginal productivity. These assumptions therefore help to control the first and the second order conditions of the optimization problem of the input providers. These restrictions are typically met by any iso-elastic production function.

of organic production is constrained by two balancing effects, a "learning-by-doing" effect, and a "niche market" effect".

The "learning-by-doing" effect implies that the productivity gap between both sectors is decreasing with the number n of farmers who adopt organic production. In other word, we assume that $\beta(n)$ is increasing with the number n of adoptors. Moreover it also seems quite reasonable to assume that marginal contribution of a new entrant is decreasing with the number of participants in the organic sector, and perhaps even disappears if all farmers choose organic farming. In other words, we assume[2] that $\beta'(n) > 0$, $\beta"(n) < 0$ and $\lim_{n \to N} \beta'(n) = 0$. We nevertheless maintain the idea that $\beta(N) < 1$: organic farming remains less productive than conventional farming. Thus, this cannot justify the emergence of an organic agricultural sector *per se*.

The "niche market" effect is related to the fact that some consumers are willing to pay more for organic products. Since we essentially concentrate on the supply side we do not explicitly model this behavior. We simply assume that the price $p(n)$ at which farmers sell their organic products depends on the number of adoptors and is, at least for the first mover, attractive enough, i.e. $p(0) > p_c$. However, because we wish to capture the idea that we are on a "niche market", we also assume that this potential advantage decreases with the number of farmers producing organic products, and even at a increasing rate. For this reason, we require $p'(n) < 0$, $p"(n) < 0$ and that $\lim_{n \to 0} p'(n) = 0$.

Following Fulton and Giannakas (2001) and Hayenga (1998), the *upstream input providers*, indexed by $j = 1, \ldots, m$, are assumed to wield significant market power on the input markets. We distinguish two markets: one for organic seeds and one for bundles of seeds and chemical since these two inputs enter in a fixed proportion in the conventional production function. Each firm delivers both inputs by taking as given the quantities provided by the other firms. We denote by s_j^o and s_j^c the the amount of organic seeds and of the bundle chosen by firm j.

We finally assume that these two goods are produced at a constant marginal cost, and we denote by c_0 and c_b respectively for the organic seeds and the bundle of seeds and chemicals. Moreover we assume that $c_o < c_b$, which means that the production cost of organic seed is lower than the production cost of a bundle composed of conventional seeds and chemicals. This gives, of course, a competitive advantage to organic farming, but one has to keep in mind that these input providers do not sell their product at the marginal cost : they try to capture a part of the farmers' profits.

[2]For simplicity, we consider n as a continuous variable.

The *timing of the game* in this Cournot Oligopoly context is quite usual. As in a standard entry model, farmers decide first wether they want to produce organic products or develop a conventional farming activity. Since entry is free, this choice is simply driven by the comparison of the expected profits of moving from one sector to another. In the second step, the upstream firms choose their optimal supply for both kind of seeds, having in mind that they deliver a bundle of seeds and chemicals to the conventional farmers and anticipate the impact of their strategic choice on the price of both products. In a third and final step, the conventional, as well as the organic farmers choose competitively the amount of organic seeds and the bundle of conventional seeds and chemicals they want to use. We seeking a subgame perfect equilibrium of this game. This allows us to identify the conditions inducing the existence of an organic farming sector, and to design the public policy rules supporting the development of organic farming.

3 The equilibrium of the inputs sector

In this section, we take the distribution of the farmers between the two sectors as given and look at the quantity of organic and conventional seeds that are traded. In other words, we focus on the last two steps of the game. This gives us the opportunity to compute the profits realized by each player and to prepare the discussion on the emergence of an organic production sector.

Let us first begin with the competitive behavior of the two types of farmers. A standard profit maximizing condition tells us that each farmer purchases seeds until his marginal productivity is equal to the purchase price. Those conditions are written as:

$$\begin{cases} p(n) \cdot (\beta(n) \cdot f'(s_o)) = p_s \\ p_c \cdot f'(s_c) = p_b \end{cases} \tag{1}$$

respectively for organic and conventional farmers. Keeping in mind that all farmers are symmetric within each sector, we immediately obtain the following inverse demand functions:

$$P_s\left(S_0, k(n)\right) = k(n) \cdot f'\left(\frac{S_o}{n}\right) \tag{2}$$

$$P_b\left(S_c, p_c\right) = p_c \cdot f'\left(\frac{S_c}{N-n}\right) \tag{3}$$

where S_0 and S_c stand for the aggregated demand for organic and conventional seeds and $k(n) := p(n) \cdot \beta(n)$.

In the Cournot game context, the input providers set their optimal supply of organic seeds s_o^j and the bundle of conventional seeds and chemicals s_c^j in such a way to maximize their profits. In other words, a Nash equilibrium of this game is given by: $\forall j = 1, \ldots, m$

$$\left(\tilde{s}_o^j, \tilde{s}_c^j\right) \in \underset{\left(s_o^j, s_c^j\right)}{\arg\max} \left(P_s \left(\sum_{j=1}^{m} s_o^j, k(n) \right) - c_o \right) \cdot s_o^j + \left(P_b \left(\sum_{j=1}^{m} s_c^j, k(n) \right) - c_b \right) \cdot s_c^j \tag{4}$$

This yields the following first order conditions:

$$\forall j = 1, \ldots, m \qquad \begin{cases} k(n) \cdot f" \left(\frac{1}{n} \sum_{j=1}^{m} s_o^j \right) \cdot \frac{s_o^j}{n} + \left(k(n) \cdot f' \left(\frac{1}{n} \sum_{j=1}^{m} s_o^j \right) - c_o \right) = 0 \\ p_c \cdot f" \left(\frac{1}{N-n} \sum_{j=1}^{m} s_c^j \right) \cdot \frac{s_c^j}{N-n} + \left(p_c \cdot f' \left(\frac{1}{N-n} \sum_{j=1}^{m} s_c^j \right) - c_b \right) = 0 \end{cases} \tag{5}$$

Moreover, under the technical assumption (the elasticity $e_{f"}(s)$ of $f"$ is larger than -2), these conditions are necessary and sufficient for optimality (see appendix A).

If markets clear at a Cournot equilibrium and farmers are symmetric within each sector, we can say that $\frac{1}{n} \sum_{j=1}^{m} s_o^j$ and $\frac{1}{N-n} \sum_{j=1}^{m} s_c^j$ are, respectively, the amount of seed s_o and s_c used by an organic and a conventional farmer at the Cournot equilibrium. If we carry out this change of notation, we immediately observe from equation (5) that the equilibrium production levels are identical for each input provider and are given by:

$$\forall j = 1, \ldots, m \quad \left(s_o^j, s_c^j\right) = \left(n \cdot \left(\frac{f'(s_o) - \frac{c_o}{k(n)}}{-f"(s_o)} \right), (N-n) \cdot \left(\frac{f'(s_c) - \frac{c_b}{p_c}}{-f"(s_c)} \right) \right) \tag{6}$$

Summing up these quantities over all input providers and again making use of the previous market clearing conditions, a Cournot equilibrium of the input providing game can be obtained by simply solving for (s_o, s_c) the following system:

$$\begin{cases} \frac{1}{m} \cdot f"(s_o) \cdot s_o + f'(s_o) = \frac{c_o}{k(n)} \\ \frac{1}{m} \cdot f"(s_c) \cdot s_c + f'(s_c) = \frac{c_b}{p_c} \end{cases} \tag{7}$$

Under our assumptions, the conclusion follows:

Lemma 1 *This system has a unique solution for (s_o, s_c). Thus there exists a unique Cournot equilibrium of the input provider game.*

The previous Lemma is a rather technical (but necessary) result on the existence and uniqueness of a solution. It allows us to fully characterize the quantities that are traded and even to construct the profit of the farmers and the input providers for any distribution of farmers between the organic and the conventional sectors.

In fact, by equation (7), we know that the equilibrium demand for seeds of an organic and a conventional farmer can be described by two functions, $s_o\left(\frac{c_o}{k(n)}, m\right)$ and $s_c\left(\frac{c_b}{p_c}, m\right)$, which relate the quantity of seeds used in each sector to the number m of input provider and to the relative profitability of each sector measured by the ratio of the cost over the price (but taking into account the learning-by-doing effect). We can even observe:

Proposition 1 *The equilibrium quantities of seeds in the organic sector,* $s_o\left(\frac{c_o}{k(n)}, m\right)$ *and in the conventional one,* $s_c\left(\frac{c_b}{p_c}, m\right)$ *used by a representative farmer are decreasing respectively with the ratio* $\frac{c_o}{k(n)}$ *and* $\frac{c_b}{p_c}$*, and increasing with the degree of competition measured by the number* m *of input providers. Moreover as* $m \to \infty$*, these quantities converge toward the competitive equilibrium quantities given respectively by* $s_o\left(\frac{c_o}{k(n)}\right) = (f')^{-1}\left(\frac{c_o}{k(n)}\right)$ *and* $s_c\left(\frac{c_b}{p_c}\right) = (f')^{-1}\left(\frac{c_b}{p_c}\right)$.

Recalling that each farmer behaves competitively by adjusting the marginal gain obtained from the seeds to its price (see equation 1), we can easily compute the profit of each type of farmers. These profit functions are given by:

$$\begin{cases} \pi_o\left(k(n), c_o, m\right) = k(n) \cdot \left[f\left(s\right) - f'\left(s\right) \cdot s|_{s_o\left(\frac{c_o}{k(n)}, m\right)} \right] = k(n) \cdot \gamma\left(s\right)|_{s_o\left(\frac{c_o}{k(n)}, m\right)} \\ \pi_c\left(p_c, c_b, m\right) = p_c \cdot \left[f\left(s\right) - f'\left(s\right) \cdot s|_{s_c\left(\frac{c_b}{p_c}, m\right)} \right] = p_c \cdot \gamma\left(s\right)|_{s_c\left(\frac{c_b}{p_c}, m\right)} \end{cases} \tag{8}$$

We also observe that profits are non negative since for all neoclassical production functions $f(s)$ the marginal productivity is always lower than the average productivity[3] so that $\gamma(s) := f(s) - f'(s) \cdot s \geq 0$.

In the same vein, we can also compute from lemma 1 the quantities of organic and conventional seeds sold by each input provider. By rearranging equation (6) these quantities are given by:

$$\begin{cases} s_o^j\left(\frac{c_o}{k(n)}, m, n\right) = \frac{n}{m} \cdot s_o\left(\frac{c_o}{k(n)}, m\right) \\ s_c^j\left(\frac{c_b}{p_c}, m, n\right) = \frac{(N-n)}{m} \cdot s_c\left(\frac{c_b}{p_c}, m\right) \end{cases} \tag{9}$$

[3]This directly follows from the absence of "free lunch" (i.e $f(0) = 0$) and the concavity of f.

and the profit of each seed provider is given by:

$$\pi\left(k(n), c_o, p_c, c_b, m, n\right) = \frac{1}{m^2}\left(\begin{array}{c} n \cdot k(n) \cdot \left[-f"\left(s_o\left(\frac{c_o}{k(n)}, m\right)\right)\right] \cdot \left(s_o\left(\frac{c_o}{k(n)}, m\right)\right)^2 \\ +(N-n) \cdot p_c \cdot \left[-f"\left(s_c\left(\frac{c_b}{p_c}, m\right)\right)\right] \cdot \left(s_c\left(\frac{c_b}{p_c}, m\right)\right)^2 \end{array}\right) \quad (10)$$

Those results are, in some sense, usual. In fact, following Saitone, Sexton and Sexton (2008), we observe that the introduction of imperfect competition among the upstream sellers in the seed sector has important distributional impacts. Upstream market power (measured by the inverse of the number m of input providers) classically reduces the amount of seeds used in both the organic and the conventional sector (see lemma 2) with respect to a competitive situation. It also modifies the profits distribution because the input providers are able to capture a part of the profit of the farm contrary to a pure competitive situation in which constant returns to scale typically reduce their profit to zero. Of course, this effect disappears when the number of input providers becomes large. In that case, the quantities traded converge to the competitive outcome (see lemma 2) and the profit of the input providers goes to zero (see equation 10).

4 The free entry equilibrium

We now move to the issue of the distribution of the different farmers between organic and conventional activity and to the conditions that ensure the emergence of organic farming as a plausible alternative to conventional agriculture. Moreover, this will give us the opportunity to assess, in the next section, some public policy intervention that sustain the development of organic farming.

4.1 The free entry equilibrium distribution

We must first define an equilibrium concept in order to construct this distribution. Under free entry, the equilibrium distribution of farmers between both sectors is reached if no farmer (expecting higher return) is willing to move to the other sector. The free entry condition is quite simple to define since the profit of the conventional farmer (see equation 8) is independent of the number of organic farmers. This means that an equilibrium distribution is reached for a n^* with the property that :

$$\begin{cases} \pi_o\left(k(n^*), c_o, m\right) \geq \pi_c\left(p_c, c_b, m\right) \\ \pi_c\left(p_c, c_b, m\right) \geq \pi_o\left(k(n^*+1), c_o, m\right) \end{cases} \quad (11)$$

In this case, no organic farmer is willing to turn into a conventional one and reciprocally no conventional farmer is willing to change his activity. If, for the sake of simplicity, we consider n as a continuous variable, this means that we have to find an n satisfying the following two properties:

$$\begin{cases} \pi_o\left(k(n^*), c_o, m\right) = \pi_c\left(p_c, c_b, m\right) \\ \pi_o\left(k(n^*), c_o, m\right) \text{ is decreasing at } n^*. \end{cases} \tag{12}$$

If we want to study this equilibrium distribution, it becomes important to investigate the behavior of the profit of organic farmers when n changes. By computing this partial derivative, we obtain:

$$\frac{\partial \pi_o}{\partial n} = k'(n) \cdot \left[\left(\gamma(s)|_{s_o\left(\frac{c_o}{k(n)},m\right)} \right) - \left(\left.\frac{d\gamma}{ds}\right|_{s_o\left(\frac{c_o}{k(n)},m\right)} \right) \cdot \frac{\partial s_o}{\partial\left(c_0/k(n)\right)} \cdot \frac{c_o}{k(n)} \right] \tag{13}$$

We also know that:

- $\gamma(s) \geq 0$ since the marginal productivity is lower than the average one,
- by proposition 1, $s_o\left(\frac{c_o}{k(n)}, m\right)$ is decreasing with $(c_0/k(n))$ and,
- by computation $\frac{d\gamma}{ds} = -f"(s) \cdot s \geq 0$

We can therefore assert that the sign of $\frac{\partial \pi_o}{\partial n}$ is the same as the sign of $k'(n)$. In other words, the fact that $\pi_o\left(k(n), c_o, m\right)$ is decreasing or not with n is essentially explained by the interaction of the progressive learning process $\beta(n)$ and the constant erosion of the advantage due to the "niche" market measured by $p(n)$. If we now have in mind that the first effect has decreasing return with the number of farmers who adopt organic farming, i.e. $\beta"(n) < 0$, while the erosion of the niche benefits increases with the numbers of organic farmers, i.e. $p'(n) < 0$ and $p"(n) < 0.$, we can expect that:

Lemma 2 *The profit function of an organic farmer is $\cap$-shaped in n. It is first increasing because of the gain from the learning process, then dominated by the losses induced by the erosion of the price in the niche market. The learning effect works up to a critical number $n_{\max}$, while the erosion of the price will dominate after that number.*

This $\cap$-shaped profit function has several consequences on the emergence of organic farming. First, if, at the critical number $n_{\max}$, this profit is lower than the returns obtained in the conventional sector, i.e.

$$\pi_o\left(k(n_{\max}), c_o, m\right) < \pi_c\left(p_c, c_b, m\right) \tag{14}$$

an organic farmer sector will never emerge. This situation occurs simply because the maximal gain induced by the learning process never compensate the productivity losses specific to organic farming. If condition 14 is not met, this nevertheless does not imply that organic farming occurs for sure. Because of this ∩-shaped property, it may happen that the profit of the first farmer which moves to organic farming remain lower than the returns of conventional agriculture, i.e.

$$\pi_o\left(k(1), c_o, m\right) < \pi_c\left(p_c, c_b, m\right) \tag{15}$$

In this case, we typically have two equilibrium distributions :

- one with both organic and conventional farming (or even only organic farming if $\pi_o\left(k(N), c_o, m\right)$ is greater than $\pi_c\left(p_c, c_b, m\right)$).
- one in which only conventional farming occurs simply because the first mover to organic farming, which benefits from any learning effect, is not able to compensate his productivity losses by the additional gain induced by the "niche" market.

Finally if both conditions (14) and (15) are not satisfied we can expect that there exists a unique distribution of the farmers between both sectors (or only organic farming if $\pi_o\left(k(N), c_o, m\right) \geq \pi_c\left(p_c, c_b, m\right)$).

4.2 The emergence of organic farming under imperfect competition

In this subsection, we go a step further in the understanding of the emergence of organic farming by identifying sufficient conditions that bring together the costs of the up-stream seed providers, the prices for organic and conventional products and the learning by doing effect.

Let us first start with the simplest case in which the organic farming sector has no competitive advantage with respect to the conventional one, i.e.

$$\forall n, \quad \frac{c_o}{p(n)\beta(n)} > \frac{c_b}{p_c} \tag{16}$$

One may typically expect that organic farming never occurs. The mechanism which leads to this situation is however different from a competitive one and is driven by the equilibrium behavior of the up-stream imperfectly competitive firms. Since they are aware of this competitive advantage, they a quantity strategy that favors conventional farmers. This follows directly from equation 7 and equations 2 3: under condition (16) and for any distribution n of the farmers between both sector, they are willing to sell fewer seeds at a higher price to organic farmers. This immediately reduces the profit opportunity of organic farming. Moreover, since we have assumed that $c_o < c_b$, equation 16 implies that $\forall n$, $p(n)\beta(n) < p_c$, i.e. the combination of the learning-by-doing and the "niche" market effect never reaches the price level for conventional products. This last drawback on the output market definitively relegates organic farming.

At *contrario,* is tempting to think that if the organic farmers have, for at least one distribution n, a competitive advantage then organic farming is a potential outcome. This intuition, due to imperfect competition, is again wrong. In this case, even if the up-stream seed providers now favor the organic farmers by selling more seeds at a lower price, they also capture a larger part of their profits (see equation 10 by having in mind that $e_{f''}(s) > -2$). From that point of view, we have, in our general setting[4], to make sure the organic farmers can sell their products at a higher price on the "niche market" and/or benefits from the learning-by-doing effect, i.e. $\exists n$, $p(n)\beta(n) \geq p_c$.

In other words, we can say :

Proposition 2 *Let $n_{\max}$ be defined as in lemma 2. Concerning the emergence of organic farming we can say that:*
(i) if $\max_n p(n)\beta(n) \in \left[0, \frac{c_o}{c_b} \cdot p_c\right[$ organic farming never occurs,
(ii) if $\max_n p(n)\beta(n) \in \left]p_c, \infty\right[$ there is always an equilibrium distribution of the farmers that involves organic farming,
(iii) if none of these conditions is satisfied, organic farming occurs if and only if

$$\pi_o\left(k(n_{\max}), c_o, n_{\max}, m\right) \geq \pi_c\left(p_c, c_b, m\right)$$

Moreover, even if there exists a free entry equilibrium distribution that involves organic farmers (case ii and iii), there may also be another equilibrium with only conventional farming simply because there is no advantage for the first mover to organic farming. To rule out this case, we have to verify that $\pi_o\left(k(1), c_o, m\right) \geq \pi_c\left(\frac{c_b}{p_c}, m\right)$.

The last remark of the previous proposition is linked to the fact that the profit of organic farmers is $\cap$-shaped. If the last condition is not met, the development of organic farming can

[4] Since we work with a general production function we can only give sufficient condition. A more precise threshold could be computed with a constant elasticity production function.

therefore suffer from a lack of coordination: a situation which has to be taken into account if a policy maker wants to support organic farming. But, before we move to this issue, we first present some properties of our equilibrium.

4.3 Equilibrium with organic farming

Since we are primarily interested in organic farming, we henceforth assume that

$$\pi_o\left(k(n_{\max}), c_o, n_{\max}, m\right) \geq \pi_c\left(p_c, c_b, m\right)$$

in order to ensure there always exists a equilibrium that sustains organic farming; equilibrium can be characterized by three main equations

$$\begin{cases} \phi(s_o) := \frac{1}{m} \cdot f"(s_o) \cdot s_o + f'(s_o) = \frac{c_o}{p(n)\cdot\beta(n)} \\ \phi(s_c) := \frac{1}{m} \cdot f"(s_c) \cdot s_c + f'(s_c) = \frac{c_b}{p_c} & \text{with } \gamma(s_c) = f(s) - f'(s)s \\ p(n) \cdot \beta(n) \cdot \gamma(s_o) = p_c \cdot \gamma(s_c) \end{cases}$$

The two first equations summarize the optimal behavior of the providers (see equation 7) while the last one directly follows from the entry condition. Moreover we also recall that ϕ is decreasing while γ is increasing.

This gives us the opportunity to underscore several properties of an equilibrium with organic farming. From the entry mechanism, we can obviously deduce that the profits will be the same for each kind of farmer. But this last condition also gives us the opportunity to go a step further in the characterization of an equilibrium. Let us first remember that we have assumed that the unit production cost of organic seeds is lower than the one of a bundle of seeds and chemical, i.e. $c_0 < c_b$. We now assume that the price of conventional products is equal to the price of organic food deflated by the productivity loses, , i.e. $p_c = p(n) \cdot \beta(n)$. We immediately deduce from the optimal behaviors of the providers that they sell more seeds to the organic farmers simply because $\frac{c_o}{p(n)\cdot\beta(n)} < \frac{c_b}{p_c}$ and $\phi(s)$ is decreasing. But if we now add into the picture the fact that $\gamma(s)$ is increasing, we cannot be at a free-entry equilibrium since the profits of the organic farmers are higher than those of the conventional ones. This induces entry, and contributes to a decrease of $p(n) \cdot \beta(n)$. We can therefore claim that at equilibrium the price of organic products deflated by the productivity loses, i.e. $k(n) = p(n) \cdot \beta(n)$ is always lower than the one for conventional products p_c. By taking this result for granted, we can even deduce from the free entry condition and the fact that $\gamma(s)$ is increasing, that that each organic farmer uses, at equilibrium and on a same plots of land, more seed than conventional farmer, i.e. $s_0 \geq s_c$. We can therefore state :

Proposition 3 *At a free-entry equilibrium involving organic farming, we observe that:*
(i) the price of organic products deflated by the productivity loses is lower than the price for conventional products i.e. $p(n^*) \cdot \beta(n^*) \leq p_c$*;*
(ii) Organic farming requires more seed per plots of land i.e. $s_o^* \geq s_c^*$

5 Public policy supporting the emergence of organic farming

As the main argument for support is of the "infant industry" type, we will focus here on the impact of policy instruments on the level of the organic production, and on the distribution of farms between two sectors. Using criteria like social welfare variation could be more appropriate in a stationary regime, but would requires information on consumer's surplus not accounted for in our model. It is however well-known that, under imperfect competition some instruments could prove to be inefficient or even have perverse effects. As a consequence we organize our discussion in two steps: we first present the main instruments and their basic effects and in a second step we discuss their global impact on our virtual agricultural sector.

5.1 The set of candidate instruments

First it may happen that the externalities induced by the combination of the "learning-by-doing" process and the decreasing gain obtained from the "niche" market premium results in an equilibrium precluding organic farming. This situation could occur even if organic farming is viable simply because the profit of the first mover to organic farming is lower than the profit of a conventional farmer. There is, in other words, a coordination problem that bars organic farming. This situation can nevertheless be overcome by improving the information on organic farming and by developing extension services and farmer associations. The idea is to reduce the inhibition of the first mover and to motivate enough farmers to move together toward organic farming in order to benefit of a greater learning-by-doing effect. We must nevertheless concede that the efficiency of this policy is typically inversely related to the size of the smallest coalition that will realize a higher profit under organic farming i.e. made from the minimal number $n_{\min}$ of agents such that

$$\pi_o \left(k(n_{\min}), c_o, n_{\min}, m\right) \geq \pi_c \left(p_c, c_b, m\right) \tag{17}$$

If a coalition composed of $n_{\min}$ agents moves to organic farming, a natural entry mechanism guarantees that an equilibrium with organic farming will be selected. That argument is typically one of the type of "supporting infant industry".

As soon such an equilibrium occurs, a public agency can also decide to support organic farming by using more standard instruments. We can for instance consider taxation on chemicals, a subsidy for chemical free seeds, a subsidy for organic food production or eventually an improvement of the learning curve. These different instruments can by easely introduced in our model:

- a tax per unit of chemical sold modifies the unit production cost c_b of the bundle by some τ (which of course takes into acount the proportion of chemicals in the bundle) since this tax is indirectly paid by input providers.
- a subsidy σ per unit of chemical-free seed bought by organic farmers reduces their cost. This is measured by p_s the price of organic seed (see equation 1). But inspecting equations (2) and (4), this reduces the inverse demand function by σ . As a consequence, this is formally equivalent to reducing the unit production cost c_o by σ,
- a subsidy δ per unit of organic food provides a new return for organic farmers that can be added to the price $p(n)$ in equation (2)
- impacts of changes in the learning curve are more difficult to capture: we simply state that this curve shifts up by some λ so that we replace $\beta(n)$ by $\beta(n)+\lambda$

By recalling equations (7) and (12) and by assuming that we look at a new equilibrium in the neighborhood of a interior equilibrium distribution (i.e. $n^* < N$), the effect of these policy instruments can be measured by applying the implicit function theorem to:

$$\begin{cases} \phi(s_o) := \frac{1}{m}\cdot f"(s_o)\cdot s_o + f'(s_o) = \frac{c_o-\sigma}{\kappa(n)} \\ \phi'(s_c) := \frac{1}{m}\cdot f"(s_c)\cdot s_c + f'(s_c) = \frac{c_b+\tau}{p_c} \\ \kappa(n)\cdot\gamma(s_o) = p_c\cdot\gamma(s_c) \end{cases} \tag{18}$$

$$\text{with } \kappa(n,\delta,\lambda) = (p(n)+\delta)(\beta(n)+\lambda)$$

and we can show by computation that:

Proposition 4 *If we consider an equilibrim in the neighborhood of an interior distribution of the farmers between both sectors, we can summarize the effect of the different policy instruments on* *the production level of the different types of farmers and on the equilibrium distribution between both sectors in the following table:*

	Tax on chemicals ($\partial\tau$)	Subs. for chemical free seeds ($\partial\sigma$)	Subs. for organic products ($\partial\delta$)	Improving learning by doing ($\partial\lambda$)
Seeds used by an organic farmer (∂s_0)	$-\frac{\gamma'(s_c)\cdot\phi(s_o)}{D\cdot\phi'(s_c)\cdot\kappa(n,\delta,\lambda)}<0$	$-\frac{\gamma(s_o)}{D\cdot\kappa(n,\delta,\lambda)}>0$	0	0
Bundles.used by a conventional farmer (∂s_c)	$\frac{1}{\phi'(s_c)\cdot p_c}<0$	0	0	0
Distribution of the farmers (∂n)	$\frac{\gamma'(s_c)\cdot\phi'(s_o)}{D\cdot\phi'(s_c)\cdot\partial_n\kappa(n,\delta,\lambda)}>0$	$\frac{\gamma'(s_o)}{D\cdot\partial_n\kappa(n,\delta,\lambda)}>0$	$-\frac{\beta(n)+\lambda}{\partial_n\kappa(n,\delta,\lambda)}>0$	$-\frac{p(n)+\delta}{\partial_n\kappa(n,\delta,\lambda)}>0$

with $D = [\phi'(s_o)\gamma(s_o) - \gamma'(s_o)\phi(s_o)] < 0$

5.2 Effects of the different policy instruments

We first examine a tax on chemicals. This instrument has a very indirect and contrasted effect on organic farming. Taxing chemicals increases the price of seeds/chemicals bundle by (see equation 1):

$$\frac{\partial p_b}{\partial\tau} = \frac{\partial}{\partial\tau}\left(p_c\cdot f'(s_c)\right) = p_c\cdot f"(s_c)\cdot\frac{\partial s_c}{\partial\tau} > 0$$

since the non-competitive seeds providers simply try to maintain their margins. This reduces the profits of the conventional farmers and provides incentives to move to organic farming. But entry in the organic sector reduces the benefits expected from this "niche" market and when an equilibrium with organic farming occurs, this last effect dominates the potential gain from learning-by-doing. This means that even if the taxation of chemicals increases the number of organic farmers ($\frac{\partial n}{\partial\tau} > 0$ in the previous table), it also contributes to decrease the profit of each unit of production simply because the free-entry mechanism stops only as the profit in the two sectors are the same.

Subsidies for chemical free seeds have a more clear-cut effect on organic farming. If this subsidy is paid to the organic farmers, the seeds providers will have an incentive to decrease their margin on chemical-free seeds in order to sell more to each farmer and therefore capture a part of this subsidy. This is why the price for organic seeds decreases by (see equation 1):

$$\begin{aligned}\frac{\partial p_o}{\partial\sigma} &= \frac{\partial}{\partial\tau}\left(\kappa(n,\delta,\lambda)\cdot f'(s_o)\right)\\ &= \frac{\partial\kappa(n,\delta,\lambda)}{\partial n}\cdot\frac{\partial n}{\partial\sigma}\cdot f'(s_o) + \kappa(n,\delta,\lambda)\cdot f"(s_o)\cdot\frac{\partial s_o}{\partial\sigma}\\ &= \frac{f(s_o)\cdot f"(s_o)}{-D} < 0\end{aligned}$$

Since a remaining share is left to the organic farmers, this sector becomes more attractive and entry occurs ($\frac{\partial n}{\partial \sigma} > 0$ in the previous table) until this additional gain is eliminated. We therefore end up with more organic farmers who earn the same profit as in the situation without subsidies. This last point is essentially due to the fact that input providers do not change their strategy on the conventional seed market since

$$\frac{\partial s_c}{\partial \sigma} = 0 \text{ and therefore } \frac{\partial p_b}{\partial \tau} = 0$$

Even if some conventional farmers move to the organic sector and reduce the demand for conventional seeds, these input providers will benefit from the capture of the subsidy given to these new organic farmers.

The two last instruments (subsidies for organic production or investments that improve the learning-by-doing) have rather similar effects that are mainly explained by the free entry assumption and the existence of imperfect competition on the input markets. Adjustments that are induced by such policies are quite simple : subsidies to organic production or investment in learning-by-doing improve the profitability of organic farming since $\kappa(n, \delta, \lambda) = (p(n) + \delta)(\beta(n) + \lambda)$ increases. So if nothing else changes, this induces entry until $\kappa(n, \delta, \lambda)$ comes back to its initial level in order to equalize profits in both sectors. This can of course be easily checked:

$$\begin{aligned} \frac{d\kappa(n, \delta, \lambda)}{d\delta} &= \frac{\partial \kappa(n, \delta, \lambda)}{\partial n} \cdot \frac{\partial n}{\partial \delta} + \frac{\partial \kappa(n, \delta, \lambda)}{\partial \delta} \\ &= \frac{\partial \kappa(n, \delta, \lambda)}{\partial n} \cdot \frac{-(\beta(n) + \lambda)}{\partial_n \kappa(n, \delta, \lambda)} + \beta(n) + \lambda = 0 \end{aligned}$$

From that point of view, most of the public spending goes to the development of organic farming since the input providers do not adjust their margin behavior in order to capture the additional profit, contrary to the previous case. To understand why the input providers do not try to capture a part of these subsidies, we revisit the basic equations that specify their behavior (equation 7). We immediately observe that these firms do not adapt their behavior on the conventional seeds market so that the profit of each of these farmers remains constant. For organic seeds, the story is quite different since equation 7 says that

$$\frac{1}{m} \cdot f"(s_o) \cdot s_o + f'(s_o) = \frac{c_o}{\kappa(n, \delta, \lambda)}$$

This means that if no entry occurs, any increase of $\kappa(n, \delta, \lambda)$ due to additional subsidies increases the quantity of seeds sold to each farmer in order to capture a part of this subsidy. But when entry occurs and when the distribution is close to an equilibrium with organic farming, we know that $\kappa(n, \delta, \lambda)$ decreases so that the input providers have now an incentive do decrease s_o. This mechanism works until the initial level of traded seeds is reached.

6 Concluding remarks

In this paper, we have examined the viability conditions of organic farming under an imperfect competition. While most of the research dealing with the issue of organic farming has adopted an empirical approach and focused on farmers and farms characteristics, we rely instead on a theoretical approach. Our model is based on a set of six major assumptions : (i) the farmers are homogenous in all respects, (ii) they are free to adopt conventional or organic farming (iii) they face an oligopolistic seeds and chemical industry which provides both chemicals free seed or a bundle of seed and pesticides (iiii) the existence of a niche market effect (v) a learning-by-doing process for organic farmers which partially compensates the technical gap between organic and conventional technologies and (vi) pure competition on the market for conventional products.

By using free-entry conditions and backward solving of the game, we have been able to spell out precise conditions for the emergence of organic farming. These conditions depend on the degree of competition among the upstream firms, the cost of production of chemicals-free seeds and the cost of production of the bundle of seeds and chemical for conventional production, and the prices for both products. We then examined the impacts of several policy instruments to support the emergence of organic production. They are motivated by environmental considerations and by the desire to protect an "infant industry". We examined four plausible instruments and analysed their impact on the level of production and on the distribution of farms between organic and conventional production. We introduced a tax on the bundle of chemicals and seeds, a subsidy for chemical free seeds, a subsidy to the organic production and support of the learning by doing process. All the selected instruments increase the share of organic sector but have different impacts on profits distribution .

Indeed, because most of the farmers in developped countries face concentrated agro-bussiness firms, our results have some degree of generality. This general framework could be used to examine the conditions of emergence and of diffusion of several innovations under imperfect competition. However, some assumptions are specific to the game theoretical approach. For instance, we assumed that all the farmers are homogenous, and only motivated by the same goal, profit maximization. The choice of technology by farmers could be also driven by individual preferences. Moreover, our approach has focused on the supply side, and does not explore the demand side in much detail. Eventually this choice could be updated to account for a quickly growing demand for organic products.

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APPENDIX

A The sufficient conditions for optimality

Let us observe that the Hessian matrix of the profit function is given by $H = \begin{bmatrix} A & 0 \\ 0 & B \end{bmatrix}$ with

$$\begin{cases} A = k(n) \cdot \left(f^{(3)} \left(\frac{1}{n} \sum_{j=1}^{m} s_o^j \right) \cdot \dfrac{s_o^j}{n^2} + (1 + \frac{1}{n}) \cdot f^{(2)} \left(\frac{1}{n} \sum_{j=1}^{m} s_o^j \right) \right) \\ B = p_c \cdot \left(f^{(3)} \left(\frac{1}{N-n} \sum_{j=1}^{m} s_c^j \right) \cdot \dfrac{s_c^j}{(N-n)^2} + \left(1 + \frac{1}{N-n} \right) \cdot f^{(2)} \left(\frac{1}{N-n} \sum_{j=1}^{m} s_c^j \right) \right) \end{cases}$$

where $f^{(n)}$ stands for the n^{th} derivative. Now remember that under market clearing the amount of seeds used by an organic farmer is $s_o = \frac{1}{n} \sum_{j=1}^{m} s_o^j$, the same being true for conventional farming hence $s_c = \frac{1}{N-n} \sum_{j=1}^{m} s_c^j$. If we carry out this change of variables and introduce $e_{f''}(s) := \frac{f^{(3)}(s) \cdot s}{f^{(2)}(s)}$ the elasticity of f", the previous Hessian becomes:

$$H = \begin{bmatrix} \dfrac{k(n)}{n} \cdot f^{(2)}(s_o) \left(e_{f''}(s_0) \cdot \dfrac{s_o^j}{n \cdot s_0} + 1 + n \right) & 0 \\ 0 & \dfrac{p_c}{N-n} \cdot f^{(2)}(s_c) \cdot \left(e_{f''}(s_c) \cdot \dfrac{s_c^j}{(N-n) \cdot s_c} + 1 + N - n \right) \end{bmatrix}$$

If both diagonal terms are negative, H is negative definite. Since $f^{(2)}(s) < 0$, it remains to check that

$$\begin{cases} e_{f''}(s_0) \cdot \dfrac{s_o^j}{n \cdot s_0} + 1 + n > 0 \\ e_{f''}(s_c) \cdot \dfrac{s_c^j}{(N-n) \cdot s_c} + 1 + N - n > 0 \end{cases} \tag{19}$$

This result is of course obvious when $e_{f''}(s) \geq 0$. So let us consider the case in which $e_{f''}(s) < 0$. Now let us first observe that at an optimal strategy of a Cournot player markets always clear. We can therefore say that $n \cdot s_0$ and $(N-n) \cdot s_c$ are the aggregated quantities of the two kinds of seeds that are supplied, so that $\dfrac{s_o^j}{n \cdot s_0}$ and $\dfrac{s_o^j}{(N-n) \cdot s_c}$

are market shares which belong by construction to $[0,1]$. Moreover n and $N-n$ are both greater than 1 otherwise one sector would not be activated. Finally remember that we have assumed that $e_{f"}(s) > -2$. If we make use of the three remarks, it immediately follows that conditions (19) holds

B Proof of Lemma 1

Let us define $\phi(s,m,K) := \frac{1}{m} \cdot f"(s) \cdot s + f'(s) - K$. It is easy to observe that:

$$\frac{\partial \phi(s,m,K)}{\partial s} = \frac{1}{m} \cdot f^{(3)}(s) \cdot s + f^{(2)}(s) \cdot \left(1 + \frac{1}{m}\right) = \frac{1}{m} \cdot f^{(2)}(s) \cdot (e_{f"}(s) + 1 + m) < 0$$

since $f^{(2)}(s) < 0$, $e_{f"}(s) > -2$ and $m \geq 1$. Moreover we notice that:

- $\lim_{s \to 0} \phi(s,m,K) = f'(s) \cdot \left(\frac{1}{m} \cdot e_{f'}(s) - \frac{K}{f'(s)}\right) = +\infty$ since $\lim_{s \to 0} f'(s) = +\infty$ and $e_{f'}(s)$ remains bounded.
- $\lim_{s \to +\infty} \phi(s,m,K) = -K$ since $\lim_{s \to +\infty} f'(s) = 0$.

We can therefore state that there exists a unique solution in $s\,(m,K)$ to $\phi(s,m,K) = 0$ and the lemma is obtained by applying the preceding argument to each equation of system (7)

C Proof of Proposition 1

Let us come back to the definition of $\phi(s,m,K)$ given in lemma 1. If we now apply the implicit function theorem, we immediately observe that :

$$\frac{\partial s\,(m,K)}{\partial m} = \frac{\frac{1}{m^2} \cdot f"(s)}{\frac{\partial \phi(s,m,K)}{\partial s}} > 0 \quad \text{and} \quad \frac{\partial s\,(m,K)}{\partial K} = \left(\frac{\partial \phi(s,m,K)}{\partial s}\right)^{-1} < 0$$

which proves the first part of the proposition. Let us now push m to infinite, the equation $\phi(s,m,K) = 0$ simply becomes $f'(s) - K = 0$ since $e_{f'}(s)$ is bounded. Hence $s = (f')^{-1}(K)$.

D Proof of Lemma 2

The proof of Lemma 2 is immediate. Remember that the *sign* $\left(\frac{\partial \pi_o\,(k(n), c_o, m)}{\partial n}\right) = sign\,(k'(n))$. So let us study $k(n) = p(n) \cdot \beta(n)$. By computation we obtain:

$$k'(n) = p'(n) \cdot \beta(n) + p(n) \cdot \beta'(n) \tag{20}$$

$$k"(n) = p^{"}(n) \cdot \beta(n) + 2 \cdot p'(n) \cdot \beta'(n) + p(n) \cdot \beta"(n) \tag{21}$$

Now let us observe that:

- $k"(n) < 0$, since we have assumed that $p'(n) < 0$ and $p^{"}(n) < 0$, $\beta'(n) > 0$ and $\beta"(n) < 0$.

- $\lim_{n\to 0} k'(n) > 0$ because $\lim_{n\to 0} p'(n) = 0$ and $\beta'(n) > 0$
- $\lim_{n\to N} k'(n) < 0$ because $\lim_{n\to N} \beta'(n) = 0$ and $p'(n) < 0$

We conclude that there exists a unique n_0 verifying $k'(n_0) = 0,$ and therefore such that $\dfrac{\partial \pi_o\left(k(n_0), c_o, m\right)}{\partial n} = 0.$ Moreover, since $k"(n) < 0$, $\pi_o\left(k(n_0), c_o, m\right)$ is $\cap$-shaped.

E Proof of Proposition 2

(i) Assume that $\max_n p(n)\beta(n) < \frac{c_o}{c_b} \cdot p_c$, This means that $\forall n$, $\frac{c_o}{p(n)\beta(n)} > \frac{c_b}{p_c}$ and we can deduce from Lemma 1 that $\forall n$, $s_o\left(\frac{c_o}{k(n)}, m\right) < s_c\left(\frac{c_b}{p_c}, m\right)$. If we now remember that $\gamma(s) := (f(s) - f'(s)\cdot s)$ is increasing since $\gamma'(s) = -f"(s)\cdot s$, we can say that $\forall n$, $\gamma\left(s_o\left(\frac{c_o}{k(n)}, m\right)\right) < \gamma\left(s_c\left(\frac{c_b}{p_c}, m\right)\right)$. Now remember that $c_o < c_b$, this implies, in case (i), that $\forall n$, $p(n)\beta(n) < p_c$. It remains to mix these two observations in order to say that:

$$\forall n, \quad \pi_o\left(k(n), c_o, m\right) = p(n)\cdot\beta(n)\cdot\gamma\left(s_o\left(\frac{c_o}{k(n)}, m\right)\right) < p_c\cdot\gamma\left(s_c\left(\frac{c_b}{p_c}, m\right)\right) = \pi_c\left(p_c, c_b, m\right)$$

It is impossible to observe an equilibrium distribution which involves organic farming.
(ii) if $\max_n p(n)\beta(n) \in]p_c, \infty[$ and since $c_o < c_b$, we can say that $\forall n$, $\frac{c_o}{p(n)\beta(n)} < \frac{c_b}{p_c}$. With the same arguments as in point (i) and by simply reversing the inequalities we can conclude that $\forall n$, $\pi_o\left(k(n), c_o, m\right) > \pi_c\left(p_c, c_b, m\right)$, i.e. organic farming always dominates conventional agriculture.
(iii) if none of these conditions is satisfied, organic farming occurs if and only if $\pi_o\left(\frac{c_o}{k(n_{\max})}, n_{\max}, m\right) \geq \pi_c\left(\frac{c_b}{p_c}, m\right)$ because π_0 is $\cap$-shaped with respect to n.

F Proof of Proposition 4

Let us recall that the outcome of our model can be reduced to three equations : the modified first order conditions of the input providers, i.e. equations (7) and the free entry condition, i.e. equation (12). These equation, after the introduction of the different policy arguments are sumerized in equation (18). However to simplifly the notations let us introduce $\phi(s) = \frac{1}{m}\cdot f"(s)\cdot s + f'(s)$, $\gamma(s) = f(s) - f'(s)\cdot s$ and . $\kappa(n, \delta, \lambda) = \left(k(n) + \delta\beta(n) + \lambda p(n)\right)$. We can even notice that (i) $\phi'(s) < 0$ see lemma 1, (ii) $\gamma'(s) = -f"(s)\cdot s > 0$ and (iii) $\partial_n\kappa(n, \delta, \lambda) < 0$ by construction. This last point requires an additional comment. In the comparative static excercice we are looking at what happen in a neighborhood of an equilibrium wich has the property that $n^* \in]0, N[$ and that all policy argument are set to 0. So by construction at the equilibrium $\partial_n\kappa(n, \delta, \lambda) < 0$, and since we apply the Implicite Function Theorem (IFT) from a local point of view, we can choose the neighborhoods such that $\partial_n\kappa(n, \delta, \lambda) < 0$ at the new equilibrium.

Now let build the function:

$$\Phi(s_o, s_c, n, \tau, \sigma, s, \lambda) = \left(\phi(s_o) - \frac{c_o - \sigma}{\kappa(n, \delta, \lambda)},\ \phi(s_c) - \frac{c_b + \tau}{p_c}, \kappa(n, \delta, \lambda)\cdot\gamma(s_o) - p_c\gamma(s_c)\right)$$

And since an equilibrium is given by $\Phi(s_o, s_c, n, \sigma, \tau, s) = 0$, let us apply the IFT. By a simple exercice of computation and by bearing in mind that $\phi(s_o) = \frac{c_o - \sigma}{\kappa(n)}$, we observe that :

$$\partial_{(s_o,s_c,n)}\Phi = \begin{bmatrix} \phi'(s_o) & 0 & \frac{\phi(s_o)\cdot\partial_n\kappa(n,\delta,\lambda)}{\kappa(n,\delta,\lambda)} \\ 0 & \phi'(s_c) & 0 \\ \kappa(n,\delta,\lambda)\cdot\gamma'(s_o) & -p_c\cdot\gamma'(s_c) & \partial_n\kappa(n,\delta,\lambda)\cdot\gamma(s_o) \end{bmatrix}$$

and

$$\partial_{(\tau,\sigma,\delta,\lambda)}\Phi = \begin{bmatrix} 0 & \frac{1}{\kappa(n,\delta,\lambda))} & \frac{\phi(s_o)\cdot(\beta(n)+\lambda)}{\kappa(n,\delta,\lambda)} & \frac{\phi(s_o)\cdot(p(n)+\delta)}{\kappa(n,\delta,\lambda)} \\ -\frac{1}{p_c} & 0 & 0 & 0 \\ 0 & 0 & (\beta(n)+\lambda)\cdot\gamma(s_o) & (p(n)+\delta)\cdot\gamma(s_o) \end{bmatrix}$$

Now let us observe that the determinant of $\partial_{(s_o,s_c,n)}\Phi$ given by:

$$\det\left(\partial_{(s_o,s_c,n)}\Phi\right) = \phi'(s_c)\cdot\partial_n\kappa(n,\delta,\lambda)\cdot\left[\phi'(s_o)\gamma(s_o) - \gamma'(s_o)\phi(s_o)\right] < 0$$

Being non-zero, we can therefore apply the IFT and we know that $\partial_{(\sigma,\tau,\delta)}(s_o,s_c,n) = -\left(\partial_{(s_o,s_c,n)}\Phi\right)^{-1}\cdot\partial_{(\sigma,\tau,\delta)}\Phi$ (at least locally). Moreover it is a matter of fact to check that:

$$\begin{aligned} \left(\partial_{(s_o,s_c,n)}\Phi\right)^{-1} &= \frac{1}{D}\begin{bmatrix} \gamma(s_o) & -\frac{p_c\gamma'(s_c)\phi(s_o)}{\kappa(n,\delta,\lambda)\cdot\phi'(s_c)} & -\frac{\phi(s_o)}{\kappa(n,\delta,\lambda)} \\ 0 & \frac{D}{\phi'(s_c)} & 0 \\ -\gamma'(s_o)\frac{\kappa(n,\delta,\lambda)}{\partial_n\kappa(n,\delta,\lambda)} & \frac{\phi'(s_o)p_c\gamma'(s_c)}{\phi'(s_c)\cdot\partial_n\kappa(n,\delta,\lambda)} & \frac{\phi'(s_o)}{\partial_n\kappa(n,\delta,\lambda)} \end{bmatrix} \\ \text{with } D &= \left[\phi'(s_o)\gamma(s_o) - \gamma'(s_o)\phi(s_o)\right] < 0 \end{aligned}$$

We therefore obtain that:

$$\partial_{(\tau,\sigma,\delta,\lambda)}(s_o,s_c,n) = \frac{1}{D}\begin{bmatrix} -\frac{\gamma'(s_c)\phi(s_o)}{\kappa(n,\delta,\lambda)\phi'(s_c)} & -\frac{\gamma(s_o)}{\kappa(n,\delta,\lambda)} & 0 & 0 \\ \frac{D}{\phi'(s_c)\cdot p_c} & 0 & 0 & 0 \\ \frac{\phi'(s_o)\cdot\gamma'(s_c)}{\phi'(s_c)\cdot\partial_n\kappa(n,\delta,\lambda)} & \frac{\gamma'(s_o)}{\partial_n\kappa(n,\delta,\lambda)} & -\frac{(\beta(n)+\lambda)\cdot D}{\partial_n\kappa(n,\delta,\lambda)} & -\frac{(p(n)+\delta)\cdot D}{\partial_n\kappa(n,\delta,\lambda)} \end{bmatrix}$$

Since $\gamma(s), \gamma'(s), \phi(s), \kappa(n) > 0$ and $\phi'(s), \partial_n\kappa(n,\delta,\lambda) < 0$ at an equilibrium, we can conclude that:

$$sign\left[\partial_{(\sigma,\tau,\delta,\lambda)}(s_o,s_c,n)\right] = \begin{bmatrix} - & + & 0 & 0 \\ - & 0 & 0 & 0 \\ + & + & + & + \end{bmatrix}$$