Conventional vs. Alternative Farming: Assessing the Sustainability of a Regional Food Supply Pattern.

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Abstract

Feeding the world's expanding population in a sustainable way figures among the main challenges to address in the coming decades. In this paper, we wonder whether promoting alternative farming lead to improve the sustainability of the food supply chain at a regional scale. Using a spatial model describing the regional land allocation between two types of agricultural practices, we show that alternative farming is more likely to develop and thrive in regions hosting an intermediate-size city. Regarding the optimality of the market outcome, we highlight that promoting alternative farming can lead to a welfare improvement provided that the marginal opportunity cost of land at the urban fringe remains low enough. However, when looking at the environmental aspects, we find that the conversion from conventional to alternative farming does not necessarily induce a cut in GHG emissions and may, as a consequence, counterbalance the positive effect on the regional welfare.

Keywords: Food supply, Agriculture, Land allocation, Greenhouse gas, Sustainability

JEL Classification: F12; Q10; Q54; Q56; R12

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Introduction

Today's global food system is characterized by two major features: (i) food production rests on intensive agricultural practices and (ii) populations depend increasingly on food from distant sources[1]. Long-distance food supply has become the norm in most of the world, particularly in highly urbanized regions where farmland has greatly declined, forcing the cities that can not rely on local production to expand the boundaries of their foodshed (Kloppenburg et al., 1996).

However, climate change, environmental damages, so as the depletion of energy resources are truly threatening the sustainability of this system, leading the cities to account for factors that were until recently neglected. This is moreover strengthened by the fact that urban dwellers now have more specific and demanding expectations regarding the social and the ecological features of the food they consume. In affluent cities notably, the primary issue related to food is no longer one of inadequate supplies but rather one of quality and ethical concerns (Deutsch et al., 2013).

In this context, "eating locally and organically" has become one of the main watchwords for food supply planning. Cities are increasingly numerous to wonder about the relevance of developing policies to explicitly support alternative production and reduce their inter-regional dependencies (Peters et al., 2009). From a practical standpoint, improving the sustainability of their current food supply chain would broadly fall into two sets of measures:

i) Initiating changes towards less incentive agricultural practices, including organic food development and reduced reliance on fertilizer (Niggli et al. (2009); Pimentel et al. (2005)).

ii) Rebuilding the foodshed boundaries so as to shorten the food supply chain and tend toward self-reliance (local vs imported production).

Alternative food systems – *that is, systems that rely on a mix of local food production and organic farming*– are, in this respect, commonly viewed to be inherently more sustainable than the conventional system; from the ecological standpoint first, low-input practices and shorter distances associated with alternative farming are purported to reduce the amount of energy used and greenhouse gas emissions released in food transportation (Hinrichs, 2003). Regarding the economic and social dimensions then, goods from alternative systems are presumed to be sold at

[1]In the United States, food travels between 2,500 and 4,000 kilometers from farm to plate, as much as 25 percent farther than in 1980's. In the UK, food travels 50 percent farther than it did two decades ago (Halweil, 2002).

higher prices, enabling farmers to generate a greater profit and, thereby, improve the economic viability of rural communities.

In practice however, the veracity of these assertions is greatly challenged; a growing body of research questions the assumption that local food systems are intrinsically more fair or sustainable (Bellows and Hamm (2001); Born and Purcell (2006)) and supports the idea that "localness" is not always related to environmental benefits (Pirog et al., 2001)[2]. In the end, the debate over the better sustainability of alternative systems remains unresolved, the existing body of literature being not sufficient and/or too much contextual to either substantiate or refute the claims (Edwards-Jones et al., 2008).

In this paper, we develop a theoretical spatial model describing the regional land allocation between two types of agricultural practices (alternative and conventional) and we wonder whether promoting alternative farming lead to improve the sustainability of the food supply chain at a regional scale. Exploring the conditions that enable alternative farming to exist viably, we show that alternative farming is more likely to develop and thrive in regions hosting an intermediate-size city, insufficient market opportunities and expensive food transportation hindering respectively its development in rural areas surrounding small and large cities. Regarding the optimality of the market outcome, we highlight that fostering alternative farming can lead to a welfare improvement provided that the marginal opportunity cost of land at the urban fringe remains low enough. However, when looking at the environmental aspects, we find that the conversion from conventional to alternative farming does not necessarily induce a cut in GHG emissions and may, as a consequence, counterbalance the positive effect on the regional welfare.

The paper proceeds as follows. Section 1 presents the model that we use in Section 2 to determine the farming pattern that occurs at the equilibrium. In Section 3 and 4, we discuss the optimality of the market outcome and we wonder whether fostering alternative farming can concomitantly improve the regional welfare and the carbon footprint of the food supply chain. Section 5 finally offers a comparative-static analysis focused on the impacts of rising energy prices.

[2] Comparing the carbon footprint of local versus imported foodstuffs, Pirog et al. (2001) state that the higher weight capacities of transportation vehicles used in the global food system are usually more efficient due to scale. Since farmers involved in local alternatives are most often not part of a distribution network that offers more organized and efficient transport logistics for delivering food, the environmental benefit is not obvious.

1 The Model

Consider an economy formed by an open region and two sectors (agriculture and urban sector). The agricultural activity can be of two types: conventional farming, where commodities are gathered to be sold in the global integrated market, and alternative farming where goods are exclusively sold in the region they have been grown. The region hosts a population exogenously divided into λ_u urban households and λ_r farmers, $\lambda_u/(\lambda_u + \lambda_r)$ measuring the urbanization rate.

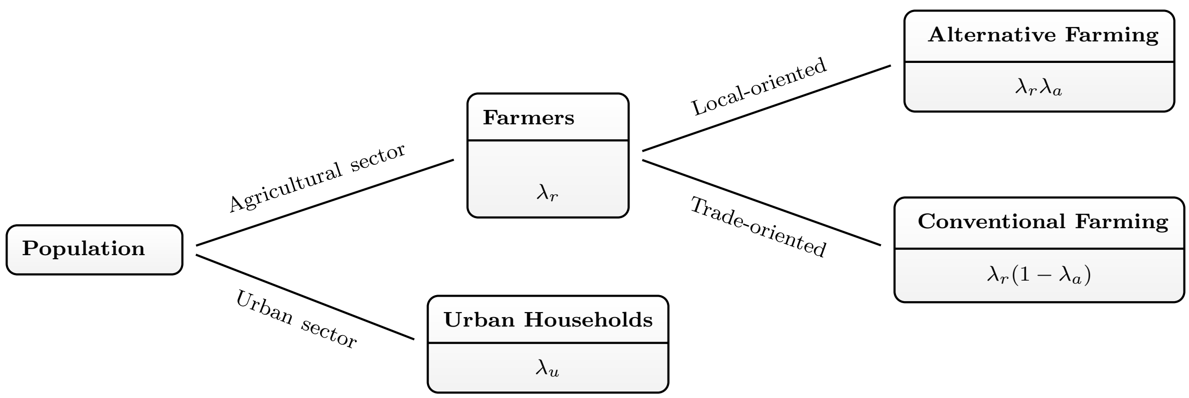

Figure 1: *The sectoral organization of the region*

1.1 The spatial structure

The regional space is made of an urban area including a CBD located at $x = 0$ and urban households' lots, and a rural area where farmers live and produce agricultural goods. Soil quality is assumed to be homogeneous over all available land. Without loss of generality, we focus on the right-hand side of the region, the left-hand side being perfectly symmetrical. Distances and locations are expressed by the same variable x, measured from the city center.

Each urban dweller consumes a residential plot of fixed size $1/\delta$ (where $\delta > 1$ is the density of the city) so that the right endpoint of the city is given by

$$\bar{x}_u = \frac{\lambda_u}{2\delta}$$

Farmers settles at the periphery of the urban area. They produce either conventional or alternative goods. Assuming they need one unit of land for cultivation each, the right endpoint of the region is:

$$\bar{x} = \frac{\lambda_u}{2\delta} + \frac{\lambda_r}{2} \tag{1}$$

We finally suppose the mass of land units is high enough to accommodate both urban and farming activities at the equilibrium. Although questionable, this assumption does not affect our conclusions on land allocation drawn from this model because alternative and conventional farming use the same quantity of land and also because the regional distribution between urban and agriculture (λ_u/λ_r) is fixed.

1.2 Preferences and demand

Preferences are defined over three consumption goods: an alternatively-grown agricultural product, a conventional agricultural product, and a homogeneous aggregate good Q, chosen as the numéraire and representing the consumption of all goods other than agricultural commodities. In order to abstract from income effects, we assume that the marginal utility with respect to the numéraire is constant. The geographical origin of conventional products is not known to consumers, so that they can not distinguish between goods produced in the region they live and those imported from abroad. We further assume that the utility function is additive with respect to the consumed quantity of agricultural goods (q_a and q_c) and the composite good (M) and given by[3]

$$U(Q; q_c; q_a) = Q + \left(\alpha_c - \frac{q_c}{2}\right) q_c + \left(\alpha_a - \frac{q_a}{2}\right) q_a - \gamma q_a q_c \tag{2}$$

The parameters α_a, α_c and γ are positive and we posit $\gamma < 1$ to ensure the quasi-concavity of the utility function. γ measures the substitutability between the two agricultural varieties, ranging from zero when alternative and conventional goods are independent, to values close to one when they are perfect substitutes. α_a and α_c represent the intrinsic quality of alternatively-grown and conventional goods, respectively. The gap between α_a and α_c is therefore a measure of the quality differentiation between the two agricultural goods and reflects the consumers' willingness to buy products identified as "alternatively -grown" ; the higher α_a compared with α_c, the larger the consumers' sensitivity towards the farming practices. On the contrary, if $\alpha_a = \alpha_c$, consumers do not value the "local and environmentally friendly" feature, considering goods from alternative production as conventional ones.

Consumers live in the urban area and work in the CBD. They bear urban costs, given by the sum of the commuting costs and the land rent. Denoting t_u and R_u as the per-mile commuting

[3] This specification is similar to that used by Singh and Vives (1984) with the simplification $\beta_i = \beta_j = 1$.

cost and the (urban) land rent, the budget constraint of a urban dweller residing at x is:

$$q_c p_c + q_a p_a + Q + R_u(x) + t_u x = w_u + \overline{Q} \tag{3}$$

where p_c and p_a are the prices of the conventional and the alternative good, and w_u is the urban wage prevailing in the city. The initial endowment in numéraire $\overline{Q}$ is supposed to be large enough to ensure strictly positive consumption at the equilibrium.

Maximizing the utility (2) subject to the budget constraint (3) leads to the following individual demand functions for alternative and conventional goods

$$q_a^d = \frac{\alpha_a - \gamma\alpha_c}{1-\gamma^2} - \frac{p_a}{1-\gamma} + \frac{\gamma}{1-\gamma^2}(p_a + p_c) \tag{4}$$

$$q_c^d = \frac{\alpha_c - \gamma\alpha_a}{1-\gamma^2} - \frac{p_c}{1-\gamma} + \frac{\gamma}{1-\gamma^2}(p_a + p_c) \tag{5}$$

1.3 Technologies and agricultural profits.

Alternative food production Alternative farming refers to organically grown products, intended for regional consumption only. Farmers operating in this network only use organic fertilizer and one unit of land to produce. Denoting by $\bar{q}$ the natural ability of soils to grow crops in the region, the individual production in alternative goods is given by:

$$q_a^s = \bar{q}\kappa \tag{6}$$

where κ is a positive coefficient that can be interpreted as the agricultural labor efficiency.

The costs to transport the goods from the farm to the city are borne by the farmer and are supposed to be linear in weight and in distance. Letting t_a be the transportation cost per unit of good and distance and $R_a(x)$, the land rent paid by a farmer involved in alternative farming, the profits of a farmer located at x are:

$$\pi_a(x) = (p_a^* - t_a x)\bar{q}\kappa - R_a(x). \tag{7}$$

As alternative farmers produce for the domestic market only, the equilibrium price is determined at the regional scale. Denoting by λ_a the share of farmers involved in alternative production, the total amount of goods produced is such that $Q_a^s = \bar{q}\kappa\lambda_r\lambda_a$. Using (4) and the expression of Q_a^s, the market clearing condition for alternatively-grown goods leads to

$$p_a^* = \alpha_a - \gamma(\alpha_c - p_c) - \left(1-\gamma^2\right)\frac{\lambda_a\lambda_r\bar{q}\kappa}{\lambda_u} \tag{8}$$

The difference $\alpha_a - \gamma(\alpha_c - p_c)$ captures the maximum willingness to pay for alternatively-grown goods, while the last term in RHS of (8) encapsulates both the effect of the competition between farmers ($\lambda_a \lambda_r \bar{q}\kappa$) and that of regional market opportunities (through the inverse measure of the demand sensitivity to price $\frac{1-\gamma^2}{\lambda_u}$).

Conventional food production In conventional farming, production requires one unit of land and an amount z of synthetic fertilizer. As in Beckmann (1972), we consider a neoclassical Cobb-Douglas production function; the yield response to synthetic fertilizer application is assumed to be positive, increasing and concave. The individual supply in conventional goods can be written as $q_c^s \equiv \bar{q}\kappa F(z)$ with $F'(z) > 0$ and $F''(z) < 0$. For simplicity, we further assume $F(z) = \sqrt{z+1}$ so that

$$q_c^s = \bar{q}\kappa\sqrt{z+1} \qquad \forall z \geq 0 \tag{9}$$

Note that when no synthetic fertilizer is used ($z = 0$), yields in conventional farming equals those of alternative farming ($q_c^s(0) = q_a^s = \bar{q}\kappa$).

Regarding the food transportation, commodities are first gathered in a regional grain elevator located at the border of conventional fields $\hat{x}$, before being brought to the central market by larger vehicles[4]. To send its production to the elevator, the farmer has to pay t_c per unit of product and distance covered. We further assume $t_c < t_a$, meaning that conventional farmers benefit from lower transportation costs than alternative farmers[5]. Let p_z and R_c be the unit cost of synthetic fertilizer and the land rent paid by conventional farmers. The profits of a farmer located at x are then given by:

$$\pi_c(x) = (p_c - t_c|x - \hat{x}|)q_c^s(x) - p_z z - R_c(x) \tag{10}$$

For simplicity, we suppose that p_c and p_z are exogenously fixed; the regional supply in conventional goods is assumed to be small enough to not significantly impact the equilibrium price p_c determined on the global market.

[4]Although other locations can be envisaged, this option offers the advantage to abstract from the effects of the location strategy within the conventional agricultural area.

[5]This assumption is consistent with the reality, the higher transport costs in the organic sub-sector being mainly due to the lack of economies of scale (CEC, 2004).

Conventional farmers choose the amount of synthetic fertilizer to be applied so as to maximize their profit $\pi_c(x)$, leading to:

$$z^*(x) = \begin{cases} \left(\dfrac{p_c - t_c|x-\hat{x}|}{2p_z}\bar{q}\kappa\right)^2 - 1 > 0 & \text{if } \hat{x} < x \leq \tilde{x} \\ 0 & \text{if } \tilde{x} < x < \bar{x} \end{cases} \tag{11}$$

and

$$q_c^{s^*}(x) = \begin{cases} \dfrac{p_c - t_c|x-\hat{x}|}{2p_z}(\bar{q}\kappa)^2 & \text{if } \hat{x} < x \leq \tilde{x} \\ \bar{q}\kappa & \text{if } \tilde{x} < x < \bar{x} \end{cases} \tag{12}$$

where $\tilde{x} \equiv \hat{x} + \dfrac{p_c}{t_c} - \dfrac{2p_z}{\bar{q}\kappa t_c}$. As shown by (11), the amount of synthetic fertilizer used by conventional farmers is decreasing with the distance from the regional grain elevator, and increasing with the natural ability of land $\bar{q}$. Moreover, the expression of $\tilde{x}$ suggests that the spatial extent of the area which accommodates conventional farms using synthetic fertilizer only depends on a set of exogenous parameters. This result, stemming from the assumption that the transportation cost from the grain elevator to the CBD is sufficiently low to be neglected, is of particular importance as it implies that conversion to alternative farming does not systematically lead to a decrease in synthetic fertilizer use (Fig. 2.2).

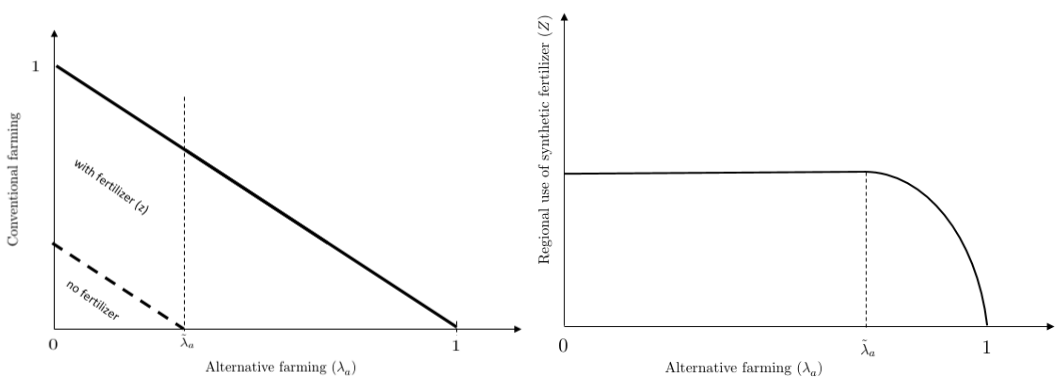

Figure 2: *Farming conversion and regional use of synthetic fertilizer*

When looking closer at the nature of the conventional farming activity, three cases can be observed according to the level of synthetic fertilizer use. First, all the conventional farmers use synthetic fertilizer if $\bar{x} < \tilde{x}$ that is, if the transportation cost per unit of good supported by the farmer located at the limit of the region is small enough. Using (1) and the expression of $\tilde{x}$, we show this condition can be written as $\frac{(1-\lambda_a)\lambda_r}{2}t_c < p_c - \frac{2p_z}{\bar{q}\kappa}$ or equivalently:

$$\lambda_a > \tilde{\lambda}_a \equiv 1 - \frac{2}{\lambda_r}\frac{\bar{q}\kappa p_c - 2p_z}{\bar{q}\kappa t_c}. \tag{13}$$

Second, if $\tilde{x} \leq \hat{x}$, or equivalently, if $\bar{q} \leq \frac{2p_z}{\kappa p_c}$, none of the conventional farmers use synthetic fertilizer[6]; in this case, the natural ability of soil is not high enough to make the use of synthetic fertilizer economically beneficial. Finally, conventional farming includes both farmers who use fertilizer and others who do not use fertilizer if $\hat{x} < \tilde{x} < \bar{x}$ (that is, if $\bar{q} > \frac{2p_z}{\kappa p_c}$ and $\lambda_a < \tilde{\lambda}_a$).

Summing up, the share of conventional farmers using synthetic fertilizer ($\lambda_{c|_{z>0}}$) is such:

$$\lambda_{c|_{z>0}} = \begin{cases} 0 \quad \text{if} \quad \bar{q} \leq \dfrac{2p_z}{\kappa p_c} \\ > 0 \quad \text{if} \quad \bar{q} > \dfrac{2p_z}{\kappa p_c} \quad \begin{cases} \dfrac{2}{(1-\lambda_a)\lambda_r}\dfrac{\bar{q}\kappa p_c - 2p_z}{\bar{q}\kappa t_c} & \text{if} \quad \lambda_a < \tilde{\lambda}_a \\ 1 & \text{if} \quad \lambda_a > \tilde{\lambda}_a \end{cases} \end{cases} \tag{14}$$

$\lambda_{c|_{z>0}}$ increases with the share of alternative farming (λ_a) provided that the natural ability of soils is high enough. Plugging (11) and (12) into (10), the profits for farmers involved in conventional production are finally given by:

$$\pi_c(x) = \begin{cases} \dfrac{(p_c - t_c|x-\hat{x}|)^2}{4p_z}(\bar{q}\kappa)^2 - R_{c|_{z>0}}(x) + p_z & \text{if } \hat{x} < x \leq \tilde{x} \\ (p_c - t_c|x-\hat{x}|)\bar{q} - R_{c|_{z=0}}(x) & \text{if } \tilde{x} < x < \bar{x} \end{cases} \tag{15}$$

2 The equilibrium pattern of agricultural land use

We now determine the agricultural pattern that would emerge at the market equilibrium. In order to lighten the calculations, we further normalize κ to one, without loss of generality.

2.1 Equilibrium land allocation

As in Von Thünen models, the regional land allocation is derived from the equilibrium rent function. Bid rent functions are obtained by equating the location costs (transportation and land cost) within each area (see Appendix B.1). Each plot of land being allocated to the highest bidder, the equilibrium land rent is such that:

$$R^*(x) = max\{R_u(x), R_a(x), R_{c|_{z>0}}(x), R_{c|_{z=0}}(x)\} \tag{16}$$

[6]Under this threshold value of $\bar{q}$, $\tilde{\lambda}_a$ is always higher than one, so that $\lambda_a < \tilde{\lambda}_a$.

Depending on the bid rent curves' ranking, several land use configurations can occur (Fig. 3). In order to ease the discussion, we conduct the rest of the analysis assuming that the intra-regional space is organized along the following scheme: a CBD surrounded by a residential urban area, followed by a zone dedicated to alternative farming, finally bordered by a conventional farming area. We show in Appendix B.2 that this spatial configuration occurs if and only if the share of alternative farmers is not to high, that is, for $\lambda_a < \hat{\lambda}_a$ with $\hat{\lambda}_a = \frac{4(2p_z t_a - \bar{q} p_c t_c)}{\bar{q} t_c^2 \lambda_r} > 0$[7]. In this case, the equilibrium land rent is given by:

$$R^*(x) = \begin{cases} R_u^*(x) = \delta t_u |\bar{x}_u - x| + R_a^*(\bar{x}_u) & \text{if } 0 < x \leq \bar{x}_u \\ R_a^*(x) = t_a |\hat{x} - x| \bar{q} + R^*_{c|_{z>0}}(\hat{x}) & \text{if } \bar{x}_u < x \leq \hat{x} \\ R^*_{c|_{z>0}}(x) = \dfrac{p_c + t_c\left(\hat{x} - \frac{x+\tilde{x}}{2}\right)}{2p_z} t_c |\tilde{x} - x| \bar{q}^2 + R^*_{c|_{z=0}}(\tilde{x}) & \text{if } \hat{x} < x \leq \tilde{x} \\ R^*_{c|_{z=0}}(x) = t_c |\bar{x} - x| \bar{q} & \text{if } \tilde{x} < x < \bar{x} \end{cases} \tag{17}$$

and illustrated by Figures 3.A1, 3.A2, and 3.A3. If the above condition is not met (i.e. if $\lambda_a > \hat{\lambda}_a$), a spatial pattern where the land allocated to alternative farming is enclosed in the conventional farming area occurs (Fig. 3.B).

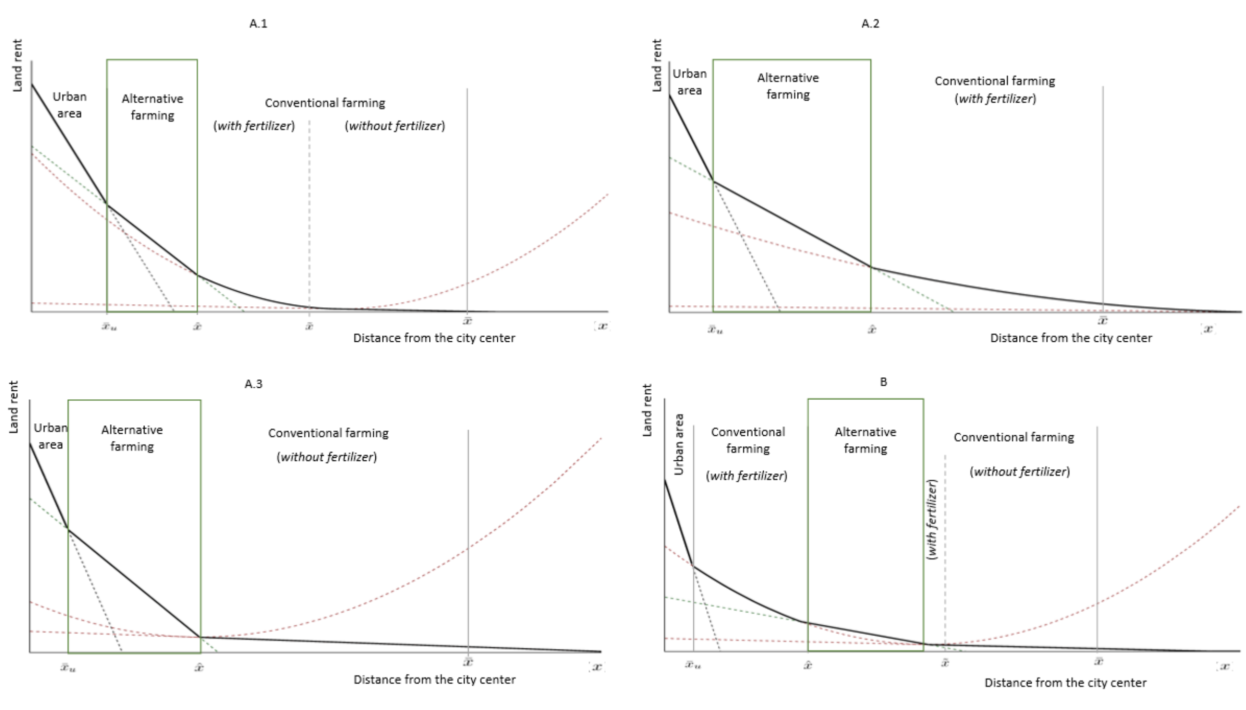

Figure 3: *Bid-rent functions and regional land allocation*

[7] Note that for values of t_c sufficiently low compared with t_a, this condition is always met.

Equilibrium incomes in alternative and conventional farming are obtained by plugging (17) into (7) and (15):

$$\pi_a^* = \left[p_a^* - t_a\left(\frac{\lambda_u}{2\delta} + \frac{\lambda_a\lambda_r}{2}\right) - \frac{(\bar{q}p_c - 2p_z)^2}{4\bar{q}p_z} - \frac{(1-\lambda_a)\lambda_r}{2}t_c\right]\bar{q} \tag{18}$$

$$\pi_c^* = \left[p_c - t_c\frac{(1-\lambda_a)\lambda_r}{2}\right]\bar{q} \tag{19}$$

Recalling that the price of alternatively-grown goods falls with the share of farmers involved in alternative farming (Eq.(8)), profits in alternative farming are decreasing with λ_a while they are increasing in conventional farming. Consequently, starting from a very low share of alternative farming (i.e. λ_a close to 0), there can be an interior solution for the regional distribution of farmers between conventional and alternative activities at the equilibrium. Such an equilibrium occurs when no farmer can be better off by converting to the other farming practice, that is when profits in conventional and alternative farming equalize. Solving $\pi_c^* = \pi_a^*$ for λ_a, we derive the equilibrium share of farmers involved in alternative farming:

$$\lambda_a^* = \frac{\alpha_a - \gamma(\alpha_c - p_c) - t_a\frac{\lambda_u}{2\delta} - \left(\frac{p_z}{\bar{q}} + \frac{p_c^2\bar{q}}{4p_z}\right)}{\lambda_r\left(\bar{q}\frac{1-\gamma^2}{\lambda_u} + \frac{t_a}{2}\right)} \tag{20}$$

Since the profit differential between alternative and conventional farming decreases monotonically as the share of alternative farmers increases, this equilibrium is unique and stable. Moreover, we show in Appendix C that λ_a^* varies from 0 to 1 for intermediate values of t_a.

2.2 Urbanization and agricultural practices

According to (20), the share of alternative farming describes a concave function with respect to the urban population' size (λ_u). This inverted U-shaped relation stems from the interplay of two competing effects, namely, the market size effect ($\frac{1-\gamma^2}{\lambda_u}$) and the transportation bill effect ($-t_a\frac{\lambda_u}{2\delta}$). In a first step, a growth in urban population leads to strengthen the market size effect; farmers are encouraged to convert to alternative production so as to benefit from additional outlets. However, the growth in urban population also leads to a residential sprawl, resulting in higher transportation costs for farmers. Since the marginal impact of the market size effect is decreasing with the urban population' size while that of the transportation bill is constant, there is a threshold level of urbanization $\bar{\lambda}_u$ at which the equilibrium share of alternative farming achieves a maximum (thereafter referred as $\bar{\lambda}_a$):

$$\bar{\lambda}_u = \frac{2\bar{q}\left(1-\gamma^2\right)}{t_a}\left[\sqrt{1+\frac{\delta}{\left(1-\gamma^2\right)\bar{q}}\left(\alpha_a-\gamma(\alpha_c-p_c)-\frac{4p_z^2+p_c^2\bar{q}^2}{4\bar{q}p_z}\right)}-1\right] \tag{21}$$

Beyond $\bar{\lambda}_u$, transportation costs outweigh the market size effect so that farmers have incentives to return to conventional production.

Proposition 2.1 *Alternative farming is more likely to develop and thrive in a region hosting an intermediate-size city than cities of large and small sizes (other things being equal).*

The shape of the relationship between alternative farming and urbanization and the value of $\bar{\lambda}_u$ are strongly influenced by the parameters that help describing the consumers' preferences. First, the quality differentiation between conventional and alternatively-grown goods affects the equilibrium farming pattern as follows: the higher the gap $(\alpha_a - \alpha_c)$, the stronger the consumers' valuation of the alternative product, and the larger the share of alternative farming, whatever the level of urbanization. Second, as illustrated by Figure 4, the value of the maximum alternative share $\bar{\lambda}_a$ is positively (resp. negatively) related to the degree of agricultural goods' substituability provided that the quality of the alternatively-grown good valuated by the consumers is high (resp. low).

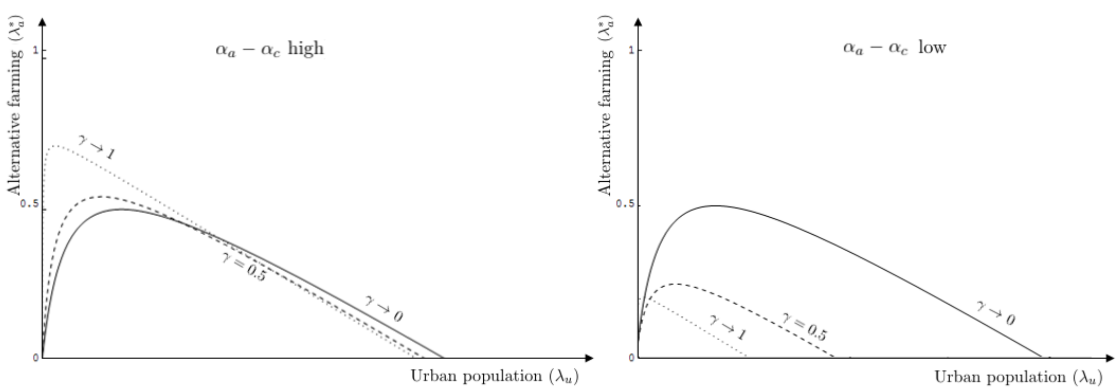

Figure 4: *Alternative farming share (λ_a^*) and urban population' size (λ_u) for different level of goods' substituability.*

Lastly, agricultural goods' substituability also determines the level of $\bar{\lambda}_u$. When agricultural goods are almost-perfect substitutes (γ close to one), the market effect is weak and quickly overtaken by the transportation bill, so that alternative farming can only develop in very low urbanized regions. As γ decreases, the market effect plays more significantly, allowing alternative farming to become economically viable in regions hosting a larger city.

2.3 Soil quality and fertilizer use at the equilibrium

As mentioned in the foregoing, the use of synthetic fertilizer in conventional farming varies in space and depends on the natural ability of the regional soils ($\bar{q}$). As a consequence, the nature of the conventional farming observed at the equilibrium differ from a region to another according to this characteristic (Fig. 5).

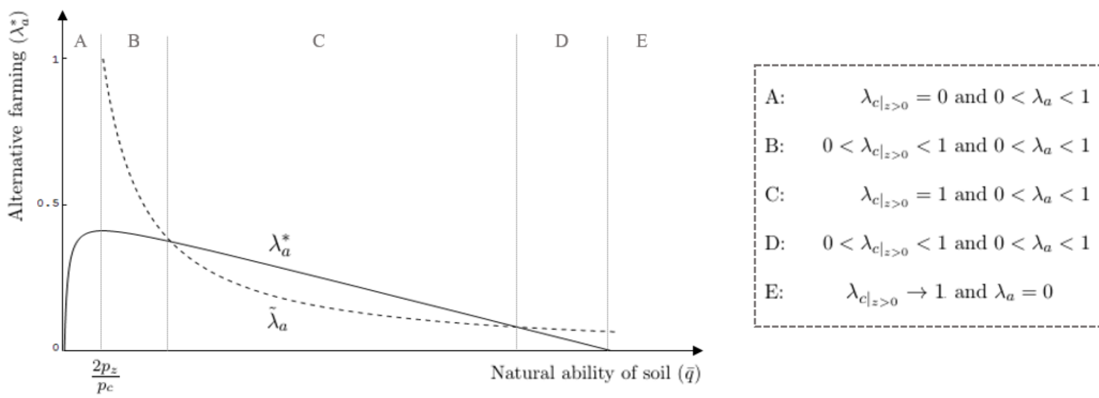

Figure 5: *The regional farming pattern at the equilibrium*

For a very low natural ability of soils, the region hosts mainly synthetic-free conventional farming. As the quality rises (while remaining below $\frac{2p_z}{p_c}$), the share of alternative farming increases. From the threshold $\bar{q} > \frac{2p_z}{p_c}$, using synthetic fertilizer in conventional production becomes economically beneficial. As a consequence, any further soils' quality increase results in the development of high-input conventional farming at the expense of both alternative and synthetic-free conventional farming. Finally, for a very large value of $\bar{q}$, farmers are all engaged in convention production and mainly use fertilizer.

3 Agricultural pattern and regional welfare

We now evaluate the optimality of the equilibrium farming pattern. We start by assessing the impact of alternative farming on the indirect utility of urban households. Afterwards, we define the farming pattern that allows maximizing the regional social welfare and we discuss the conditions for which fostering alternative farming leads to a welfare improvement.

3.1 Urban households utility and alternative farming.

Let V_u be the indirect utility of a urban household living in the region:

$$V_u = w_u - \frac{R_u^*(x)}{\delta} - t_u x + \bar{q} + CS_c + CS_a \tag{22}$$

where CS_c and CS_a are the consumers' surplus associated with the consumption of the conventional and the alternatively-grown goods, respectively. Evaluated at the equilibrium prices, the latter are given by:

$$CS_a = \left(\frac{\bar{q}\lambda_a\lambda_r}{\lambda_u}\right)^2 \frac{1-\gamma^2}{2} \quad \text{and} \quad CS_c = \left(\alpha_c - p_c - \gamma\frac{\bar{q}\lambda_a\lambda_r}{\lambda_u}\right)^2 \frac{1-\gamma^2}{2}$$

with $\frac{\partial CS_a}{\partial \lambda_a} > 0$, $\frac{\partial CS_c}{\partial \lambda_a} < 0$ for the range of values of p_c that allows the individual demand of conventional goods q_c^d to be positive, and $\frac{\partial^2 CS_a}{\partial \lambda_a^2} > \frac{\partial^2 CS_c}{\partial \lambda_a^2}$. Replacing $R_u^*(x)$, CS_a and CS_c by their expression in (22), the indirect utility becomes:

$$V_u(\lambda_a) = C - \bar{q}\left(\frac{t_a - t_c}{2\delta} + \frac{(\alpha_c - p_c)\gamma\left(1-\gamma^2\right)}{\lambda_u}\right)\lambda_r\lambda_a + \frac{\bar{q}^2\left(1-\gamma^4\right)\lambda_r^2}{2\lambda_u^2}\lambda_a^2 \tag{23}$$

where C is a constant defined as $C \equiv w_u + \frac{(\alpha_c - p_c)^2\left(1-\gamma^2\right)}{2} - \frac{(\bar{q}p_c - 2p_z)^2}{4\delta p_z} - \frac{\bar{q}t_c\lambda_r + t_u\lambda_u}{2\delta}$. The relationship between $V_u(\lambda_a)$ and λ_a being convex, the share of alternative farming that would maximize the indirect utility of urban households is a corner solution. Stated differently, the utility of urban households is maximized under full specialization only, be it either alternative or conventional.

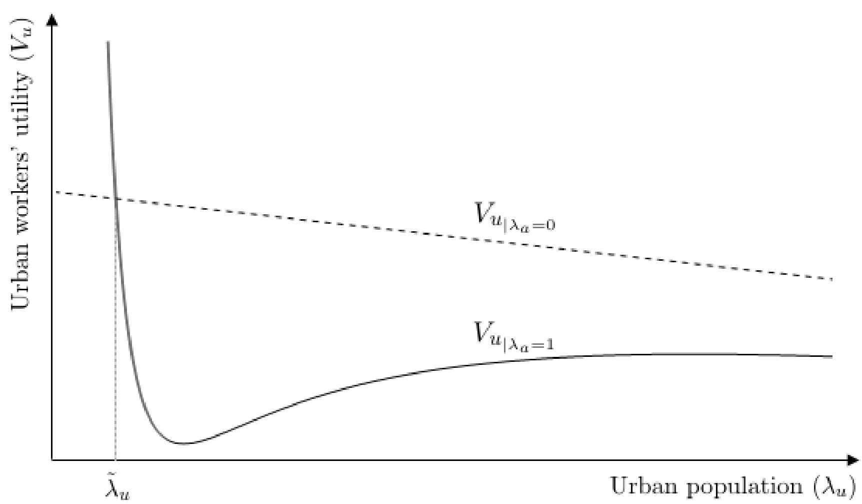

Figure 6: *Urban households' utility under fully-alternative and fully-conventional farming patterns.*

Figure 6 depicts the relationship between the indirect utility of urban households and the level of urbanization. The plain and the dashed lines represent respectively the cases where the regional agriculture is exclusively alternative ($\lambda_a = 1$) and exclusively conventional ($\lambda_a = 0$). As seen from (23), $V_{u|\lambda_a=0}$ decreases at a constant rate of $\frac{-t_u}{2\delta}$ while $V_{u|\lambda_a=1}$ describes an inverted N-shaped curve. Furthermore, since $\lim\limits_{\lambda_u \to 0} V_{u|\lambda_a=1} = +\infty$ and $\lim\limits_{\lambda_u \to +\infty} (V_{u|\lambda_a=0} - V_{u|\lambda_a=1}) = \frac{\bar{q}(t_a - t_c)\lambda_r}{2\delta} > 0$, the two curves always intersect once and only once, implying that alternative farming improves the utility of urban households only in regions hosting a city not too crowded (i.e. $\lambda_u < \tilde{\lambda}_u$).

From the urban households standpoint, alternative farming has two opposite effects. On the one hand, more farmers involved in alternative production implies both a lower price and a higher individual consumption level, leading to a larger consumers' surplus. On the other hand, alternative farming causes a rise in urban land prices; differentiating $R_u^*(\bar{x}_u)$ with respect to λ_a in (17), we show that the marginal opportunity cost of land at the urban fringe –*that is, the extra land cost that urban households have to pay for each additional alternative farmer*– is given by $\frac{\bar{q}(t_a - t_c)\lambda_r}{2\delta}$. Thus, alternative farming can either improve or reduce the urban households' utility, depending on which effect outweighs the other. Since the land costs plays with even more weight in highly urbanized regions, the development of alternative farming near large cities leads to a rise in urban land prices that cannot be positively compensated by the consumers' surplus. This explains why promoting alternative farming in the most urban-crowded may be detrimental to urban households.

3.2 *The welfare-maximizing solution*

We finally broaden the discussion on the optimality of market equilibrium by including the farmers' well-being. To this end, we define the regional social welfare function as:

$$SW(\lambda_a) = \lambda_u V_u(\lambda_a) + \lambda_a \lambda_r \pi_a^*(\lambda_a) + (1 - \lambda_a)\lambda_r \pi_c^*(\lambda_a) \tag{24}$$

with $\frac{\partial^2 SW}{\partial \lambda_a^2} < 0$[8]. Solving $\frac{\partial SW}{\partial \lambda_a} = 0$ for λ_a, the optimal share of farmers involved in alternative farming is given by:

$$\lambda_a^o = \frac{\alpha_a - \gamma(\alpha_c - p_c)(2 - \gamma^2) - t_a \frac{\lambda_u}{2\delta} - \left(\frac{p_z}{\bar{q}} + \frac{p_c^2 \bar{q}}{4p_z}\right) + t_c\left(\frac{\lambda_u}{2\delta} + \frac{\lambda_r}{2}\right)}{\lambda_r\left(\bar{q}\frac{(1-\gamma^2)^2}{\lambda_u} + t_a\right)} \tag{25}$$

Comparing (20) to (25), we can derive the conditions under which the market lead to a farming pattern close to the optimal solution. As for the equilibrium, we show in Appendix D that the

[8]Recalling that alternative and conventional profits are respectively decreasing and increasing with the share of alternative farmers and knowing that $\pi_a^*(0) > \pi_c^*(0)$, we can show that SW is a concave function of λ_a.

shape of the relationship between the optimal farming pattern and the size of the urban population (λ_u) is concave. Therefore, plotting λ_a^* and λ_a^o as a function of λ_u, curves can either cross once, twice or never cross.

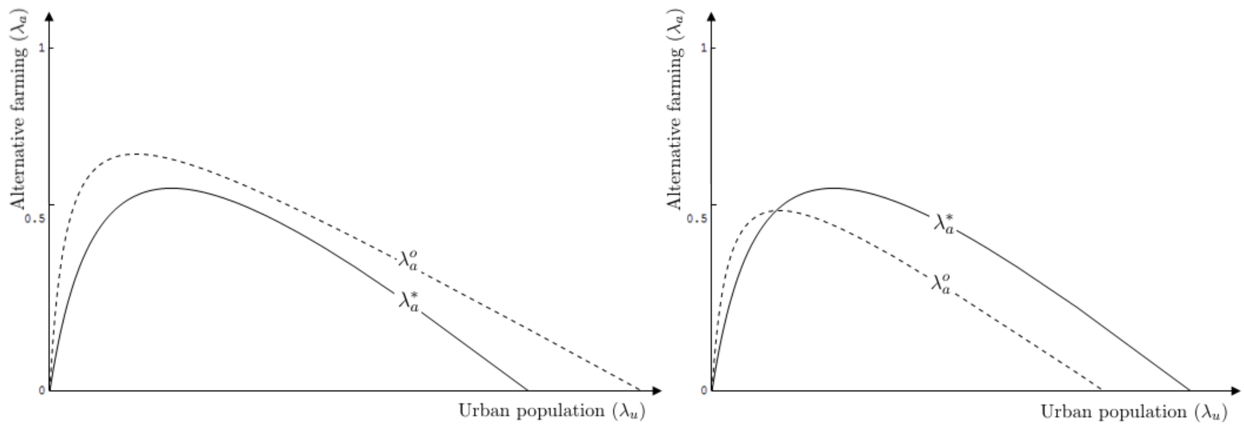

Figure 7: *Equilibrium and Optimal farming pattern in function of the urban population' size*

From (20) and (25), we get the following proprieties:

$$\lim_{\lambda_u \to +\infty} \lambda_a^o = -\infty \text{ and } \lim_{\lambda_u \to +\infty} \lambda_a^* = -\infty \tag{26}$$

$$\lim_{\lambda_u \to 0} \lambda_a^o = 0 \text{ and } \lim_{\lambda_u \to 0} \lambda_a^* = 0 \tag{27}$$

$$\lim_{\lambda_u \to +\infty} (\lambda_a^o - \lambda_a^*) = +\infty \tag{28}$$

$$\lim_{\lambda_u \to 0} \left(\frac{\partial \lambda_a^o}{\partial \lambda_u} - \frac{\partial \lambda_a^*}{\partial \lambda_u} \right) > 0 \tag{29}$$

We derive from (26) that the market always leads to an optimal situation for the most-urbanized regions, where no alternative farming can develop. Moreover, (27) and (29) suggest that the market never allows enough alternative farming to establish itself in the regions hosting a very small city. This situation can even be observed for intermediate and large cities if the marginal opportunity cost of land at the urban fringe is sufficiently low (see Fig.7.1). On the contrary, if this cost is high, alternative farming is detrimental to the utility of large-cities dwellers. In this situation, the two curves intersect and we draw from (26)–(29) that λ_a^o is always higher than λ_a^* for small values of λ_u and lower than λ_a^* for intermediate values of λ_u. Hence, from the welfare standpoint, alternative farming is not enough developed in low urbanized regions and too much developed in high urbanized regions (see Fig.7.2) [9].

Proposition 3.1 *Fostering the development of alternative farming always leads to a welfare improvement in low-urbanized regions. This result can be extended to more urbanized regions provided that the marginal opportunity cost of land at the urban fringe remains low enough.*

4 Does alternative farming development lead to a decrease in GHG emissions?

Suppose the region seeks to meet its population' food needs whilst reducing the GHG emissions stemming from the whole supply chain. As emissions come from both production and transportation, the region is torn between (i) fostering alternative farming so as to lessen the emissions due to the use of synthetic fertilizer and (ii) sharing its land between alternative and conventional production so as to curb the emissions due to the transportation flows.

In this section, we assess the way the emissions from the regional food supply vary according to the share of alternative farming and we determine the conditions for which modifying the equilibrium pattern so as to improve the social welfare contributes to a concomitant decrease in GHG emissions. It is worth noting that the emissions accounting we propose in this work differs somewhat from an environmental assessment of the food supply system of the city, as we do not include the emissions due to conventional goods grown abroad and consumed in the region. Although analytically feasible, doing so would require additional calculations to determine the share of goods produced and consumed locally and would, thereby, complicate the analysis. Instead, we focus on the volume of GHG emissions at the regional scale; we account for the emissions stemming from conventional and alternative production, food transportation within the region but also for the emissions due to incoming or out-coming flows in conventional goods (i.e. inter-regional trade, be it exports or imports). Besides, in order to avoid double-counting of emissions, we assume that the region takes into account only half of the inter-regional trade flow. Hence, summing the flows on all the regions that belong to the geographical unit we consider would give the aggregate level of emissions from the whole food supply chain.

[9] Note that λ_a^o and λ_a^* can also intersect twice before crossing the x-axis. In this case, alternative farming is not enough developed low urbanized and high urbanized regions, and too much developed in regions hosting an intermediate-size city.

4.1 Synthetic fertilizer use and agricultural production

As previously mentioned and illustrated by Figure 2, promoting alternative farming does not necessarily involve less fertilizer. According to the characteristics of the region, there may be cases where converting to alternative practices does not provide any GHG benefit in the production stage. This is readily verified by calculating the use of synthetic fertilizer and the supply in conventional goods in the region. Using (11) and (12), we have:

$$Z = \begin{cases} \dfrac{(\bar{q}p_c + 4p_z)(\bar{q}p_c - 2p_z)^2}{6\bar{q}p_z^2 t_c} & \text{if } \lambda_a < \tilde{\lambda}_a \\ \left[p_c^2 - \dfrac{4p_z^2}{\bar{q}^2} + \dfrac{t_c(1-\lambda_a)\lambda_r}{2}\left(\dfrac{t_c(1-\lambda_a)\lambda_r}{6} - p_c\right)\right]\dfrac{(1-\lambda_a)\lambda_r}{4p_z^2}\bar{q}^2 & \text{if } \lambda_a > \tilde{\lambda}_a \end{cases} \tag{30}$$

and

$$Q_c^s = 2\int_{\hat{x}}^{\bar{x}} q_c^{s*}(x)dx = \begin{cases} \dfrac{(\bar{q}p_c - 2p_z)^2}{2p_z t_c} + \bar{q}(1-\lambda_a)\lambda_r & \text{if } \lambda_a < \tilde{\lambda}_a \\ \dfrac{\bar{q}^2}{p_z}\left(p_c - \dfrac{t_c(1-\lambda_a)\lambda_r}{4}\right)\dfrac{(1-\lambda_a)\lambda_r}{2} & \text{if } \lambda_a > \tilde{\lambda}_a \end{cases} \tag{31}$$

As suggested by (30), a decrease in conventional farming results in a lower use of synthetic fertilizer only if the share of alternative farming is already sufficiently high (i.e. $\lambda_a^* > \tilde{\lambda}_a$), or if the conversion from conventional to alternative farming is large enough. Regarding the regional production in conventional goods, it decreases linearly with the share of alternative farming as long as the conversion involves conventional farmers who do not use synthetic fertilizer. Then, from $\lambda_a^* > \tilde{\lambda}_a$, the production falls more rapidly with increasing λ_a.

For simplicity, we limit the rest of the analysis to the most relevant and realistic case, that is the situation where all the conventional farmers use synthetic fertilizer to produce their goods ($\lambda_a > \tilde{\lambda}_a$). Hence, assuming that GHG emissions are linear with the production, the flow of emissions arising from food production is given by:

$$E_P(\lambda_a) = e_a Q_a^s + e_c Q_c^s = e_a\lambda_a\lambda_r\bar{q} + e_c\frac{\bar{q}^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2} \quad (\text{ with } \lambda_a > \tilde{\lambda}_a) \tag{32}$$

where e_c and e_a are the emission factors associated with the conventional and the alternative practices, respectively. e_c is assumed to be higher than e_a. As for the production in conventional goods, the emission flow stemming from agricultural production in the region decreases concavely as the share of alternative farming increases (Fig. 9.2).

4.2 *Intra-regional food transportation and trade*

Intra-regional food transport Alternative goods are transported to the central market located at $x = 0$ by each farmer involved in alternative production. Recalling that alternative fields are located from $\bar{x}_u$ to $\hat{x}$, the sum of alternative freight flows within the region is given by:

$$T_a = 2\bar{q}\left(\int_{\bar{x}_u}^{\hat{x}} |x - \bar{x}_u| dx + \lambda_a^* \lambda_r \bar{x}_u\right) = \frac{\lambda_a \lambda_r}{2}\left(\frac{\lambda_a \lambda_r}{2} + \frac{\lambda_u}{\delta}\right)\bar{q} \tag{33}$$

Not surprisingly, intra-regional transport flows of alternative goods increase with the regional share of alternative farming (Fig. 8.2).

In conventional farming, transportation is organized in two stages. In a first step, farmers carry their goods to the regional grain elevator located at $\hat{x}$:

$$T_c^{x \to \hat{x}} = 2\int_{\hat{x}}^{\bar{x}} q_c^{s^*}(x)|x - \hat{x}| dx = \frac{3p_c - t_c \bar{q}(1-\lambda_a)\lambda_r}{6p_z} \times \frac{\bar{q}(1-\lambda_a)^2 \lambda_r^2}{4} \tag{34}$$

The production from all the conventional farmers operating in the region is then collected and bundled in order to be sent, in a second step, to the central market:

$$T_c^{\hat{x} \to CBD} = Q_c^s \hat{x} = \left[\frac{\bar{q}^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2}\right]\left(\frac{\lambda_u}{\delta} + \lambda_a \lambda_r\right) \tag{35}$$

Because fostering the development of alternative farming has an impact on both the distance covered by farmers and the volume of agricultural goods transported from farms to the CBD, its effect on intra-regional conventional transportation is more ambiguous. Focusing on the volume effect first, raising the share of alternative farmers implies mechanically less conventional production. Recalling that $\lambda_a > \tilde{\lambda}_a$, the volume of goods transported decreases concavely as λ_a increases. Regarding the distance covered, trips decrease from conventional farms to the grain elevator, but increase from the elevator to the CBD. In the end, since both the volume and the distance fall in the first step of the conventional freight, $T_c^{x \to \hat{x}}$ is always decreasing with the share of alternative farming. In contrast, $T_c^{\hat{x} \to CBD}$ may either increase or decrease, depending on which effect outweighs the other (Fig. 8.1).

Inter-regional food trade. We finally account for the trade in conventional goods between the region and its trade partner. The perfect competition on the conventional agricultural markets implies unidirectional flows; the region is either importer, exporter, or self-reliant and the volume of trade flows can be expressed as:

$$|Q_c^s - Q_c^d| = \left| \int_{\hat{x}}^{\bar{x}} q_c^{s^*}(x)dx - q_c^d \lambda_u \right| \tag{36}$$

Letting ν be the distance between the region and its trade partner, the inter-regional flow of conventional goods is such that

$$T_c^{Trade} = \begin{cases} \left[\frac{\bar{q}^2[4p_c - t_c(1-\lambda_a)\lambda_r](1-\lambda_a)\lambda_r}{8p_z} - \left(\alpha_c - p_c - \frac{\gamma\bar{q}\lambda_a\lambda_r}{\lambda_u} \right) \lambda_u \right] \nu & \text{if } \lambda_a < \lambda_a^{X|M} \\ 0 & \text{if } \lambda_a = \lambda_a^{X|M} \\ \left[\left(\alpha_c - p_c - \frac{\gamma\bar{q}\lambda_a\lambda_r}{\lambda_u} \right) \lambda_u - \frac{\bar{q}^2[4p_c - t_c(1-\lambda_a)\lambda_r](1-\lambda_a)\lambda_r}{8p_z} \right] \nu & \text{if } \lambda_a > \lambda_a^{X|M} \end{cases} \tag{37}$$

where

$$\lambda_a^{X|M} = 1 - \frac{2\bar{q}p_c - 4\gamma p_z}{\bar{q}t_c\lambda_r} + \frac{2p_c}{t_c\lambda_r}\sqrt{\left(1 - \frac{2\gamma p_z(2p_c - t_c\lambda_r)}{\bar{q}p_c^2} + \frac{4\gamma^2 p_z^2}{\bar{q}^2 p_c^2} - \frac{2(\alpha_c - p_c)p_z t_c \lambda_u}{\bar{q}^2 p_c^2}\right)} > \tilde{\lambda}_a \tag{38}$$

is the alternative-conventional distribution for which the region is self-reliant in conventional goods. As illustrated by Figure 8.3, the impact of farming conversion on inter-regional flows depends on the trade status of the region: if the region is exporter, promoting alternative farming leads to decrease the trade flows since less farmers in the conventional activity is equivalent to less regional production (Equation (37.1)). On the contrary, if the region is importer, raising the share of alternative farming would widen the gap between the regional supply and the demand, inducing a rise in inter-regional trade flows (Equation (37.3)).

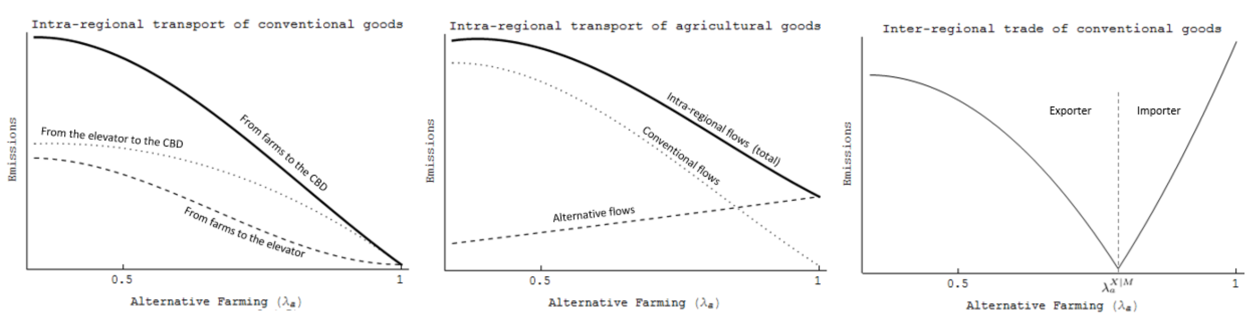

Figure 8: *GHG emissions from food transportation*

Emissions from food delivery We finally convert all these flows (expressed in weight×distance) into emissions. Let e_{ih}, e_{bh} and e_t be the emission factors associated with individual haulage, bundling haulage, and inter-regional trade flows respectively. Consistently with the reality, we further assume that the transport modes used for consolidated shipments and inter-regional trade are less emission-intensive than that used for individual transportation (i.e. $e_{bh} < e_{ih}$ and $e_t < e_{ih}$). Using (33)–(37), the total emissions stemming from food transportation are:

$$E_T(\lambda_a) = e_{ih}[T_a(\lambda_a) + T_c^{x\to\hat{x}}(\lambda_a)] + e_{bh}T_c^{\hat{x}\to CBD}(\lambda_a) + e_t\frac{T_c^{Trade}(\lambda_a)}{2} \tag{39}$$

4.3 Emissions from the regional food supply chain

Emissions and agricultural pattern   Combining (32) and (39), we finally obtain the total emissions stemming from the regional food supply system. For the sake of readability, its expression has been reported in Appendix E and we only discuss its graphical representation provided in Figure 9.

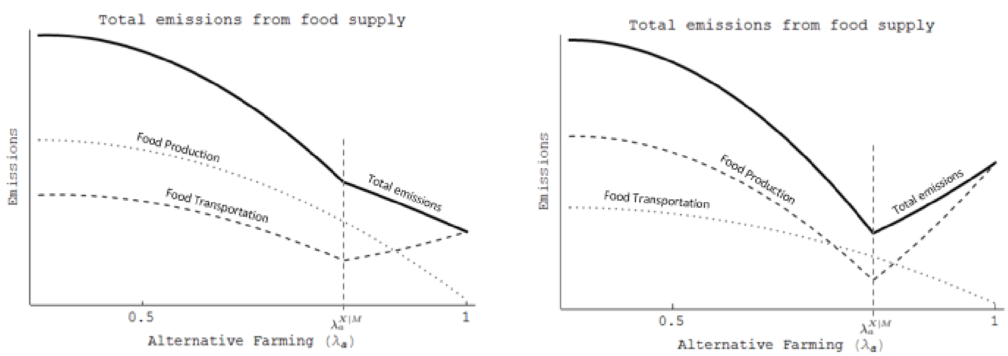

Figure 9: *Total GHG emissions from the regional food supply*

As showed by the graphs, fostering alternative farming could alternately induce less or more emissions at the regional scale. The first graph illustrates the case where emissions from inter-regional trade are negligible. Under this condition, the emissions due to conventional goods imports are more than compensated by the cut in emissions stemming from the lower use of synthetic fertilizer, so that the development of alternative farming always leads to a decrease in GHG emissions (Fig. 9.1). By contrast, if trade in conventional goods accounts for a significant part in emissions, the region is wise to limit inter-regional flows and even tend toward self-reliance. As a consequence, promoting alternative farming would induce lower emissions as long as the region is exporter in conventional goods (Fig. 9.2). In this situation, fostering the development of alternative farming so as to improve the regional welfare induces a concomitant cut in GHG emissions only provided that $\lambda_a^* < \lambda_a^o < \lambda_a^{X|M}$.

Emissions and urbanization As regards to the impact of urbanization, we can show that emissions are always increasing with the size of the urban population when the region is importer, and can either increase or decrease otherwise. λ_u has a double effect on emissions, playing both on intra-regional flows through the extent of the urban area, and on inter-regional trade through a demand effect. Hence, comparing the emissions of two exporting regions hosting a city of different size, the impact of alternative farming development is not clear; on the hand, it would increase the emissions due to intra-regional flows to a greater extent in the most-urbanized region. On the other hand however, the emissions stemming from inter-regional trade would also decrease more significantly in the largest region. The total effect is thus always conditional upon the relative importance of these two variations.

5 Assessing the impact of an energy price rising.

We finally use our model to evaluate the effects of a rise in energy prices on the regional farming pattern at the equilibrium. To do so, we assume that such an increase can affect both the fertilizer price (p_z) and the transportation costs (t_c and t_a). We suppose that technology is given, so that farmers can neither avoid nor lessen the impact of the increase in energy prices by changing their production behavior.

5.1 The impact of a fertilizer price rising

Suppose that the energy price rising leads to increase the fertilizer price (p_z). Using the results from Section 1 and 2, a basic comparative static analysis allows to draw the implications on the equilibrium farming pattern.

Assuming first that $\bar{q} > \frac{2p_z}{p_c}$, we know from (14) that farmers distribute themselves between alternative production, intensive conventional production, and synthetic-free conventional production. Starting from this farming pattern, any rise of p_z leads to an increase of λ_a^* – as π_a^* increases while π_c^* stays constant (Eqs. (18) and (19)) – and consequently, to an increase of the equilibrium value of $\hat{x}$. In the same time, as p_z rises, the equilibrium value of $\tilde{x}$ diminishes, so that the spatial extent of lands where the use of synthetic fertilizer is economically viable ($\tilde{x} - \hat{x}$) becomes smaller.

Moreover, as producing goods becomes more expensive, conventional farmers tend to lessen their use of synthetic fertilizer whatever their location (Eq. (11)). In the end, the regional use of fertilizer in conventional farming decreases because of the reduction of both the individual use $z^*(x)$ and the share of conventional farmers using fertilizer $\lambda_{c|_{z>0}}$.

The share of alternative farming keeps rising with p_z and achieves a maximum value when $\bar{q} = \frac{2p_z}{p_c}$. From this specific value, any further rise in p_z leads to a decrease in λ_a^*; alternative farmers convert to synthetic-free conventional production.

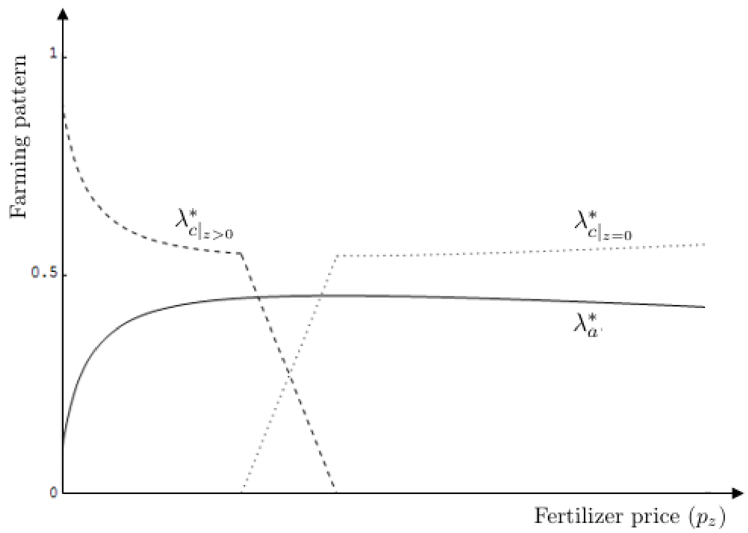

Figure 10: *The impact of a fertilizer price rising on the equilibrium farming pattern.*

Proposition 5.1 *A rise in the synthetic fertilizer price would favor the conversion to alternative farming while transforming conventional farming from high-input to reduced-input practices.*

5.2 The impact of an agricultural transport cost rising

Suppose now that the energy price rising results in higher costs of agricultural transportation for both conventional and alternative farmers (i.e. t_a and t_c). According to (20), the equilibrium share of alternative farming is decreasing with the transportation cost t_a. Hence, any measure involving a rise in t_a induces a decrease in λ_a^*. This results stems from the fact that, even though the increase in transportation costs affects both conventional and alternative farmers, profits in conventional activity decrease less sharply than those in alternative farming.

Regarding the conventional activity, we easily show from (11) that farmers use less synthetic fertilizer as t_c increases; since transporting goods becomes more expensive, conventional farmers have incentives to maintain their production $q_c^s(x)$ at a low level whatever their location x. In the same time, the share of farmers using fertilizer $\lambda_{c|_{z>0}}$ decreases as a result of the transportation cost increase. Hence, a transportation costs rising has the effect of reducing both the share of alternative agriculture and that of conventional agriculture using fertilizers. For a very sharp cost increase, agriculture in the region becomes predominantly synthetic-free conventional farming ($\lambda_{c|_{z=0}} \to 1$).

6 Conclusion

Feeding the population in a sustainable way has emerged as a growing concern for public authorities in most of developed countries. Although the trade-off is quite trivial, solutions to implement are not nearly that obvious. First, because current food supply chains have reached a high level of sophistication. Hence, when considering the environmental impact of food travels, the question of "how far ?" is as important as that of "how ?". Second, because of the tight economic linkages between countries, implying that addressing a sustainability issue occurring at a regional scale requires to adopt a much broader approach than a local-focused one. Finally, because one viable solution for some regions may not be generalizable to all, making it necessary to take into account economic and demographic characteristics such as the level of urbanization or the soils' quality.

In this paper, we have developed a model that allows accounting for the land allocation between conventional and alternative farming systems. Focusing on the market outcome, we find that, even though urbanization may promote the development of alternative goods production through a market size effect, it is more likely to foster a growth in conventional agriculture; given our spatial specification, the share of farmers involved in alternative agriculture tends to decline significantly, due to urban pressure and a fiercer competition on land market, making its development more likely in regions hosting an intermediate-size city. Regarding the optimality of the farming pattern at the equilibrium, we highlight that fostering the development of alternative farming always leads to a welfare improvement in low-urbanized regions. Moreover, we show that this result can be extended to more urbanized regions provided that the marginal opportunity cost of land at the urban fringe remains low enough.

Finally, when looking at the environmental aspects, we find that fostering alternative farming does not necessary lead to a cut in GHG emissions. In particular, we stress that promoting alternative farming when inter-regional trade in conventional goods account for a large part in emissions may lead to more emissions through spillover effects; if the region is already importer in conventional goods, raising the share of alternative farming will strengthen the food dependency of the region and result in an increase in emissions due to trade.

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Appendix A: Fertilizer use in conventional farming

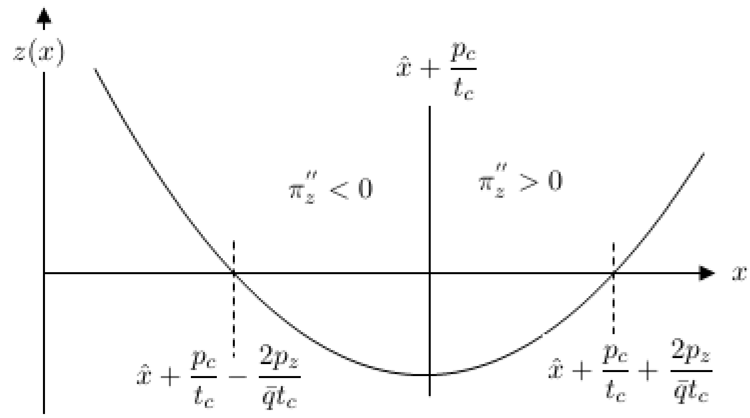

Figure 11: *Variation of synthetic fertilizer use in space*

Appendix B.1: Equilibrium land rent

Bid rents are derived by equating the location costs (transportation and land cost) within each area. For conventional farmers, the equilibrium land rent must solve $\frac{\partial \pi_c(x)}{\partial x} = 0$ or, equivalently

$$\begin{cases} \dfrac{\partial R_{c|_{z>0}}(x)}{\partial x} + \dfrac{\bar{q}^2 t_c(pc - tc|x - \hat{x}|)}{2p_z} = 0 \text{ if } x < \tilde{x} \\ \dfrac{\partial R_{c|_{z=0}}(x)}{\partial x} + \bar{q}t_c = 0 \text{ if } x \geq \tilde{x} \end{cases}$$

As a consequence, the bid rents of conventional farmers are such that

$$\begin{cases} R_{c|_{z>0}}(x) = \bar{r}_{c|_{z>0}} - \dfrac{\bar{q}^2 t_c(pc - tc|x - \hat{x}|)}{2p_z} x \text{ if } x < \tilde{x} \\ R_{c|_{z=0}}(x) = \bar{r}_{c|_{z=0}} - \bar{q}t_c x \text{ if } x \geq \tilde{x} \end{cases}$$

where $\bar{r}_{c|_{z>0}}$ and $\bar{r}_{c|_{z=0}}$ are constants. Similarly, the equilibrium land rent for alternative farmers must satisfy $\frac{\partial \pi_a(x)}{\partial x} = 0$ or, equivalently, $\frac{\partial R_a(x)}{\partial x} + \bar{q}t_a = 0$, which solution is $R_a(x) = \bar{r}_a - \bar{q}t_a x$, where $\bar{r}_a$ is a constant. Assuming that $R_a(x) > R_{c|_{z>0}}(x)$ for $x \in [0; \hat{x}[$ the (right-hand side) conventional farmers locate in the land strip $]\hat{x}, \bar{x}]$ where $\hat{x}$ is the boundary between alternative and conventional fields, and $\bar{x} = \lambda_u/(2\delta)$ is the region limit, whereas alternative farmers locate in $]\bar{x}_u, \hat{x}]$. Because the opportunity cost of land is equal to zero, the land rent at the region limit is zero, i.e. $R_c^*(\bar{x}) = 0$. This implies that $\bar{r}_{c|_{z=0}} = \bar{q}t_c\bar{x}$.

Land rents of conventional farmers using synthetic fertilizer and those who do not use fertilizer must be equal at $\tilde{x}$ (i.e., $R_{c|_{z>0}}(\tilde{x}) = R_{c|_{z=0}}(\tilde{x})$), so that $\bar{r}_{c|_{z>0}} = \bar{q}t_c(\bar{x} - \tilde{x}) + \frac{\bar{q}^2 t_c \tilde{x}\left[p_c - t_c\left(\frac{\tilde{x}}{2} - \hat{x}\right)\right]}{2p_z}$. In the same way, land rents between conventional farmers and alternative farmers must be equal at $\hat{x}$ (i.e., $R_a(\hat{x}) = R_{cz}(\hat{x})$), so that $\bar{r}_a = \bar{q}t_a\hat{x} + \bar{q}t_c(\bar{x} - \tilde{x}) + \frac{\bar{q}^2 t_c[2p_c - t_c(\tilde{x}-\hat{x})](\tilde{x}-\hat{x})}{4p_z}$.

As for urban households, they choose their location so as to maximize their utility under the budget constraint. Because of the fixed lot size assumption, the value of the consumption of the non-spatial goods $q_c p_c + q_a p_a + Q$ at the residential equilibrium is the same regardless of the urban worker's location. Denoting by t_u the commuting cost, the equilibrium urban land rent must solve $\frac{\partial V_u(x)}{\partial x} = 0$ or, equivalently, $\frac{\partial R_u(x)}{\partial x} + \delta t_u = 0$, which solution is $R_u(x) = \bar{r}_u - \delta t_u x$, where $\bar{r}_u$ is a constant. At the equilibrium, urban and agricultural land rents must be equal at the city limit $\bar{x}_u$, leading to $\bar{r}_u = \delta t_u \bar{x}_u + R_a(\bar{x}_u)$. As a result, the equilibrium land rent in the region is given by:

$$R^*(x) = \begin{cases} R^*_u(x) = \delta t_u|\bar{x}_u - x| + t_a(\hat{x} - \bar{x}_u)\bar{q} + \dfrac{\bar{q}^2(p_c - t_c\hat{x})^2}{4p_z} + p_z - (p_c - t_c\bar{x})\bar{q} & \text{if } 0 < x \leq \bar{x}_u \\ R^*_a(x) = t_a(\hat{x} - x)\bar{q} + \dfrac{\bar{q}^2(p_c - t_c\hat{x})^2}{4p_z} + p_z - (p_c - t_c\bar{x})\bar{q} & \text{if } \bar{x}_u < x \leq \hat{x} \\ R^*_{c|_{z>0}}(x) = \dfrac{\bar{q}^2(p_c - t_c x)^2}{4p_z} + p_z - (p_c - t_c\bar{x})\bar{q} & \text{if } \hat{x} < x \leq \tilde{x} \\ R^*_{c|_{z=0}}(x) = t_c|\bar{x} - x|\bar{q} & \text{if } \tilde{x} < x < \bar{x} \end{cases}$$

Appendix B.2: Intra-regional spatial patterns

Let $x_{u|a}$, $x_{u|c}$ and $x_{a|c}$ be the abscissa of the intersection point between $R^*_u(x)$ and $R^*_a(x)$, $R^*_u(x)$ and $R^*_{c|_{z>0}}(x)$, and $R^*_a(x)$ and $R^*_{c|_{z>0}}(x)$, respectively. Since $R^*_{c|_{z>0}}(x)$ is a convex function of x, alternative and conventional bid rents can intersect once or twice. Hence, two spatial configurations can occur:

i) Alternative farming develops near the urban fringe which occurs if $R^*_{c|_{z>0}}(0) < R^*_a(0)$ (implying that $R^*_a(x)$ and $R^*_{c|_{z>0}}(x)$ intersect once) or, if the first intersection between $R^*_a(x)$ and $R^*_{c|_{z>0}}(x)$ occurs before the intersection between $R^*_u(x)$ and $R^*_a(x)$ (i.e. $x^1_{a|c} < x_{u|a} < x^2_{a|c}$).

ii) The land allocated to alternative farming is enclosed in the conventional farming area which occurs if $R^*_{c|_{z>0}}(0) > R^*_a(0)$ and $x_{u|a} < x^1_{a|c} < x^2_{a|c}$.

From these conditions, we draw that alternative farming takes place at the city boundary provided that $x^1_{a|c} < x_{u|a} < x^2_{a|c}$ which leads $\lambda_a < \frac{4(2p_z t_a - p_c\bar{q}t_c)}{\bar{q}t_c^2\lambda_r}$.

Appendix C: The agricultural distribution at the equilibrium

Profits in alternative and conventional farming are given by:

$$\pi_a^* = \left[p_a^* - t_a \left(\frac{\lambda_u}{2\delta} + \frac{\lambda_a \lambda_r}{2} \right) - \frac{(\bar{q} p_c - 2p_z)^2}{4\bar{q}p_z} - \frac{(1-\lambda_a)\lambda_r}{2} t_c \right] \bar{q}$$

$$\pi_c^* = \left[p_c^* - t_c \frac{(1-\lambda_a)\lambda_r}{2} \right] \bar{q}$$

with $\frac{\partial \pi_a^*}{\partial \lambda_a} < 0$ and $\frac{\partial \pi_c^*}{\partial \lambda_a} > 0$. At the equilibrium, the farmers distribution (λ_a^*) is such that profits in conventional and alternative farming are the same. Solving $\pi_a^* = \pi_c^*$ leads to:

$$\lambda_a^* = \frac{\alpha_a - \gamma(\alpha_c - p_c) - t_a \frac{\lambda_u}{2\delta} - \left(\frac{p_z}{\bar{q}} + \frac{p_c^2 \bar{q}}{4p_z} \right)}{\lambda_r \left(\bar{q} \frac{1-\gamma^2}{\lambda_u} + \frac{t_a}{2} \right)} \tag{40}$$

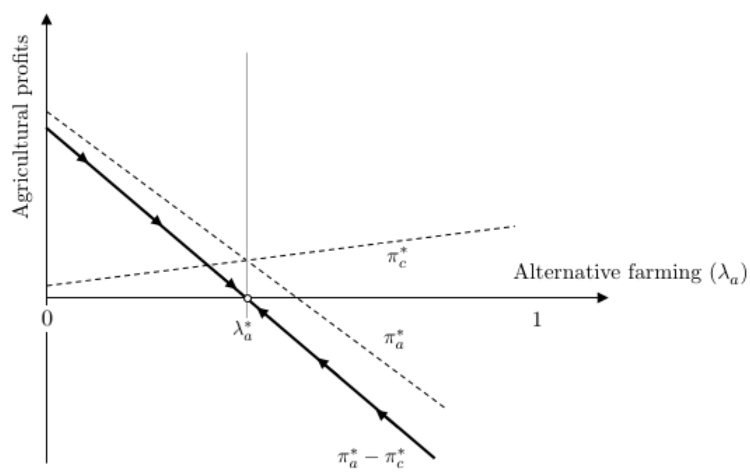

Figure 12: *Net incomes differential and equilibrium*

From (40), we derive the conditions on parameter t_a for λ_a^* to be positive and lower than 1:

$$\begin{cases} \lambda_a^* > 0 \quad \text{if} \quad t_a < \bar{t}_a \equiv \dfrac{\alpha_a - (\alpha_c - p_c)\gamma - \left(\frac{p_z}{\bar{q}} + \frac{p_c^2 \bar{q}}{4p_z} \right)}{\frac{\lambda_u}{2\delta}} \\ \lambda_a^* < 1 \quad \text{if} \quad t_a > \underline{t}_a \equiv \dfrac{\alpha_a - (\alpha_c - p_c)\gamma - \left(\frac{p_z}{\bar{q}} + \frac{p_c^2 \bar{q}}{4p_z} + \frac{\bar{q}(1-\gamma^2)\lambda_r}{\lambda_u} \right)}{\frac{\lambda_r}{2} + \frac{\lambda_u}{2\delta}} \end{cases} \tag{41}$$

Appendix D: The optimal farming pattern

Solving $\frac{\partial SW}{\partial \lambda_a} = 0$ for λ_a, the optimal share of farmers involved in alternative farming is given by:

$$\lambda_a^o = \frac{\alpha_a - \gamma(\alpha_c - p_c)(2-\gamma^2) - t_a \frac{\lambda_u}{2\delta} - \left(\frac{p_z}{\bar{q}} + \frac{p_c^2 \bar{q}}{4p_z} \right) + t_c \left(\frac{\lambda_u}{2\delta} + \frac{\lambda_r}{2} \right)}{\lambda_r \left(\bar{q} \frac{(1-\gamma^2)^2}{\lambda_u} + t_a \right)} \tag{42}$$

Let denote by N^o and D^o the numerator and the denominator of λ_a^o. Since $D^o > 0$, we posit $N^o > 0$, as the pertinent range for the study of λ_a^o is $[0;1]$. Recalling $t_a > t_c$, we get from (42) $\frac{\partial N^o}{\partial \lambda_u} < 0$, $\frac{\partial D^o}{\partial \lambda_u} > 0$, $\frac{\partial^2 N^o}{\partial \lambda_u^2} = 0$ and $\frac{\partial^2 D^o}{\partial \lambda_u^2} < 0$ so that

$$\frac{\partial^2 \lambda_a^o}{\partial \lambda_u^2} = \frac{\partial^2 D^o}{\partial \lambda_u^2} \times N^o + 2 \times \frac{\partial D^o}{\partial \lambda_u} \times \frac{\partial N^o}{\partial \lambda_u} + \frac{\partial^2 N^o}{\partial \lambda_u^2} \times D^o < 0 \tag{43}$$

As for the equilibrium, the optimal share of alternative farming is concavely related to the urban population' size.

Appendix E: The GHG emissions from the regional food supply chain

Combining (32) and (39), the total GHG emissions are given by:

$$\begin{aligned} E(\lambda_a) =& e_a\left(\bar{q}\lambda_a\lambda_r\right) + e_c\left[\frac{\bar{q}^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2}\right] + \\ & e_{ih}\left[\bar{q}\left(\frac{\lambda_a^2\lambda_r^2}{4} + \bar{q}\left(\frac{p_c}{2p_z} - \frac{t_c(1-\lambda_a)\lambda_r}{6p_z}\right)\frac{(1-\lambda_a)^2\lambda_r^2}{4}\right) + \frac{\lambda_u}{2\delta}\bar{q}\lambda_a\lambda_r\right] + \\ & e_{bh}\left[\frac{\bar{q}^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2}\left(\frac{\lambda_a\lambda_r}{2} + \frac{\lambda_u}{2\delta}\right)\right] + \\ & \frac{e_t}{2}\left|\frac{\bar{q}^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2} - (\alpha_c - p_c)\lambda_u + \gamma\bar{q}\lambda_a\lambda_r\right|\nu \end{aligned} \tag{44}$$

with $\lambda_a > \tilde{\lambda}_a$.