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Urban Foodprint and Mitigation Strategies: A Theoretical Analysis

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Urban Foo*d*print and Mitigation Strategies : A Theoretical Analysis

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Abstract

Feeding the expanding global population while reducing the environmental impact of farming and food supply is among the main challenges of the century. Cities, which host the large majority of the past decade demographic growth, are at the forefront. They are increasingly considering the relevance of developing policies to explicitly support less-intensive production and/or rebuild their *foodshed* so as to reduce their reliance on long-distance food transport. In this paper, we develop a spatial theoretical model to describe and discuss both economic and environmental implications of farming practices change and relocation strategies. We highlight that, compared to the market outcome, promoting less-intensive and local farming may improve the welfare provided that the marginal opportunity cost of urban land remains low enough. However, we also show that the conversion from conventional to alternative farming does not necessarily reduce GHG emissions and may, as a consequence, offset the positive effect on welfare. We finally conduct numerical simulations so as to illustrate the ambiguous impacts of food relocation.

Keywords: Urban Foodprint, Land Allocation, Food Supply Chains, 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 ever more intensive agricultural practices and (ii) urban populations depend increasingly on food imported from remote places [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 cannot rely on local production to expand the boundaries of their foodshed [Kloppenburg et al., 1996].

The sustainability of this system is however questioned ; the depletion of fossil energy resources and energy-related environmental damages lead cities to account for factors that were, until recently, neglected. At the same time, consumers have increasing expectations regarding the social and ecological implications of the food they purchase. In affluent cities notably, the primary issue related to food is no longer one of inadequate supply but rather one of quality and ethical concerns [Deutsch et al., 2013]. Moreover, beyond the environmental aspects, the recent Covid-19 pandemic has seriously strained supply chains and revealed that feeding cities can no longer exclusively rely on long-distance transportation.

In this context, "eating green and local" has become one of the main watchwords for food supply planning. Cities are increasingly considering the relevance of developing policies to explicitly support alternative production and reduce their inter-regional dependencies [Peters et al., 2009]. In France for instance, many local authorities have integrated a food component into their Territorial Climate-Air-Energy Plan (PCAET) and are now banking on setting up a territorial food project (PAT) [AdCF, 2021].

From a practical standpoint, improving the sustainability of their current food supply chain falls broadly into two sets of measures:

i) Reorienting incentives towards less intensive agricultural practices, including for instance support to organic farming and reduced reliance on chemical inputs [Niggli et al., 2009].

ii) Rebuilding the foodshed so as to reduce the reliance on food imports [Curtis, 2003].

Alternative Food Networks (AFNs) – *i.e., systems defined by attributes such as local production, spatial proximity between farmers and consumers, and a commitment to environmental friendly practices* – are in this respect frequently mentioned as part of the solution, since they are commonly viewed to be inherently more sustainable; 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

[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].

greenhouse gas emissions released in food transportation [Hinrichs, 2003]. Regarding the economic and the social dimensions then, goods from AFNs are thought to be sold at fairer prices through marketing channels such as community supported agriculture (CSA) or direct selling, enabling farmers to generate a greater profit and, thereby, to improve the economic viability of rural communities [Renting et al., 2003]. In practice however, these assertions are being challenged; a growing body of research questions the assumption that local food systems are intrinsically more sustainable [Born and Purcell, 2006] and supports the idea that "localness" is not necessarily environmentally-friendlier [Pirog et al., 2001][2].

In the end, the debate over the sustainability of alternative systems remains an open issue, the existing body of literature being not sufficient or too much contextual to either substantiate or refute the claims [Edwards-Jones et al., 2008]. Moreover, even though the literature on AFNs is quite extensive, covering topics such as food production sustainability [see e.g. Pacini et al. [2003]; van der Vorst et al. [2009]] or farmers decision making [see e.g. Pietola and Lansink [2001] ; Kerselaers et al. [2007]], it is yet under-theorized, the current contributions being mostly empirical [Sonnino and Marsden, 2006]. In fact, there is to our knowledge no theoretical formalization able to provide some insight into the opportunities for AFNs development in the common and current context of rapid urbanization.

The objective of this paper is twofold. First, we attempt to establish the required conditions that allow alternative farming – *i.e., agriculture providing organic and locally-grown goods through direct-selling*– to develop and exist viably in the periphery of cities. Second, we examine whether promoting alternative farming always improves the sustainability of the food supply chain at a regional scale. To explore these questions, we develop a spatial theoretical model describing the regional land allocation between two types of agricultural practices: alternative farming and conventional farming (Section 1). Using the analytical solution of the spatial equilibrium derived from our model, 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 (Section 2). This result is in line with Uematsu and Mishra [2012] who suggest that the lack of economic incentives can be an important barrier for farmers to convert; focusing on the farming practices (organic vs. non-organic), these authors find that, though organic crop producers earn higher revenue, they also incur higher operating costs which may explain the recent slow-down in organic production encountered in the US. It also

[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.

agrees in some respects with Michelsen et al. [1999] who highlight that organic development is clearly tied to demand –expected to keep growing in most countries– but that conventional chains are to be the prime marketing channel for developing sales.

Regarding the optimality of the market outcome, we highlight in Section 3 that *fostering alternative farming is welfare-improving provided that the marginal opportunity cost of urban land remains low enough*. However, when looking at the environmental aspects, we find that the conversion from conventional to alternative farming does not necessarily reduce GHG emissions and may, as a consequence, counterbalance the positive effect on the regional welfare (Section 4). Section 5 finally offers a comparative-static analysis focused on the impacts of rising energy prices. We derive that, although the rises in fertilizer cost and transportation cost both lead to transform the conventional farming from high-input to reduced-input production, they may have an opposite effect on alternative farming development.

1 An analytical framework

Consider an economy formed by an open region hosting a total population exogenously divided into $\lambda_u > 0$ urban households and $\lambda_r > 0$ farmers, and two sectors (agriculture and urban sector). Farmers can choose between two agricultural practices:

- **Conventional farming**, producing goods that are gathered to be sold in the *global integrated* market by an *intermediary* (further referred to as *conventional goods* and indexed by c).
- **Alternative farming**, providing *green* goods –i.e. using no synthetic input– that are *directly* and *exclusively* sold in the region where they have been grown (further referred to as *alternative goods* and indexed by a).

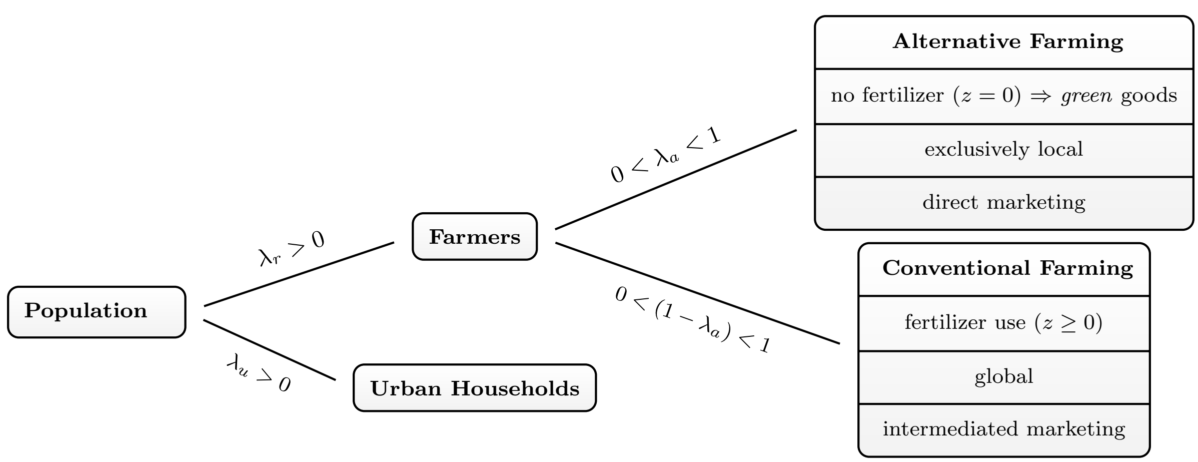

Figure 1: *The Economy*

1.1 The spatial structure

The economy is formally described by a one-dimensional space, encompassing both urban and rural areas. The region has a central business district (CBD) located in its center. Distances and locations are denoted by x and measured from this CBD. Without loss of generality, we focus on the right-hand side of the region, the left-hand side being perfectly symmetrical. The urban area is entirely used for residential purposes. Urban inhabitants are supposed to be uniformly distributed across the city and consume a residential plot of fixed size $1/\delta$, $\delta > 1$ measuring the density of the city. Thus, the right endpoint of the city is given by $\bar{x}_u = \frac{\lambda_u}{2\delta}$.

Farmers live at the periphery of the urban area and produce either conventional or alternative goods. Soil quality is assumed to be homogeneous over all available farmland and each farmer uses one unit of land for cultivation, so that the right endpoint of the region is :

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

We finally suppose that the mass of land units is large enough to accommodate both urban and farming activities at the equilibrium.[3]

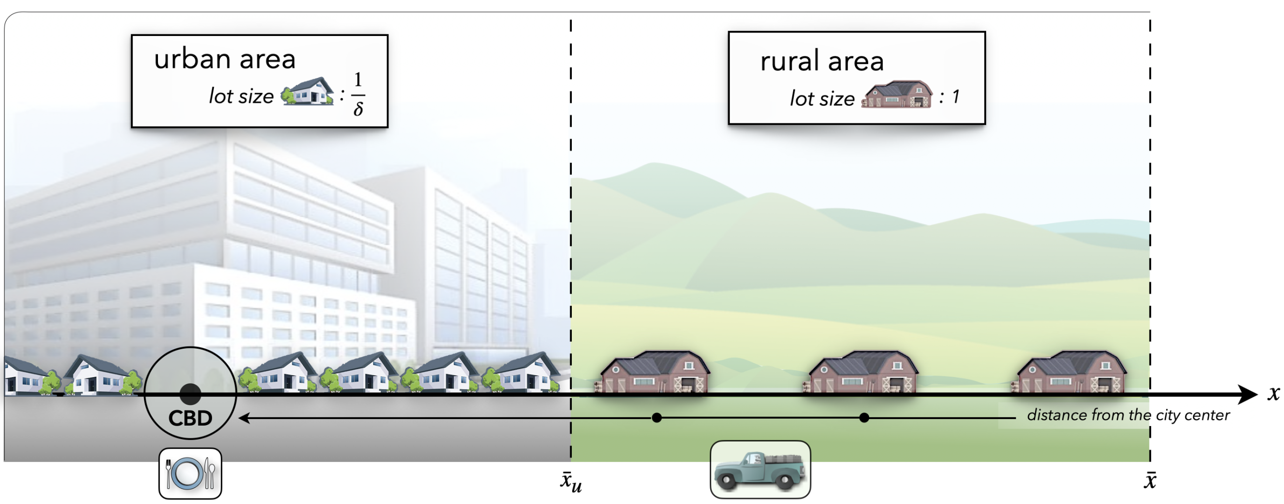

Figure 2: *Spatial organization*

1.2 Preferences and demand

Preferences are defined over three consumption goods: the conventional products, the alternative products, and a composite good Q, chosen as the numéraire. In order to abstract from differentiation

[3]Notice that, since alternative and conventional farming use the same quantity of land and the regional distribution between urban households and farmers is fixed, this assumption does not affect our conclusions on land allocation.

issues, we assume that consumers do not differentiate conventional goods produced locally from the imported goods. We further suppose that the utility function is additive with respect to the consumed quantity of agricultural goods (q_c and q_a) and the composite good (Q):

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

This specification is similar to Singh and Vives [1984] with the simplification $\beta_i = \beta_j = 1$. 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 tend to perfect substitutes. α_a and α_c represent the intrinsic quality of alternative and conventional goods, respectively. Consistently with recent studies on consumers preferences towards alternative supply chains and local food [see e.g.[Bougherara et al., 2009] ; Toler et al. [2009]], we further posit $\alpha_a > \alpha_c$. 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 alternative; the larger $\alpha_a - \alpha_c$, the greater the sensitivity of consumers towards the attributes of alternative goods.

Consumers live in the urban area and work in the CBD. They earn a same income w_u and bear urban costs, given by the commuting and housing costs. Denoting t_u and $R(x)$ as the per-mile commuting cost and the unit land rent at x, the (binding) budget constraint of a urban household residing at x is:

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

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

Maximizing the utility (2) subject to the budget constraint (3) and rearranging yields the individual demands for agricultural goods, given by the gap between the *willingness to pay* (WTP) and the market price:[4]

$$q_a^d = \frac{\alpha_a - \gamma(\alpha_c - p_c) - p_a}{1 - \gamma^2} = \frac{WTP_a - p_a}{1 - \gamma^2} \quad \text{and} \quad q_c^d = \frac{\alpha_c - \gamma(\alpha_a - p_a) - p_c}{1 - \gamma^2} = \frac{WTP_c - p_c}{1 - \gamma^2} \tag{4}$$

Aggregated demands for agricultural goods are such that $Q_a^d = \lambda_u q_a^d$ and $Q_c^d = \lambda_u q_c^d$.

1.3 Farming practices and agricultural profits.

Alternative food production Products from alternative farming are intended for regional consumption only. Farmers operating in this sector only use their labor and one unit of land to produce. Denoting

[4] Note that $\frac{\partial WTP_i}{\partial \alpha_i} > 0$, $\frac{\partial WTP_i}{\partial \alpha_j} < 0$, and $\frac{\partial WTP_i}{\partial p_j} > 0$ ($i \in \{a, c\}$, $j \in \{a, c\}$, and $i \neq j$).

by $\bar{q}$ the natural ability of soils to grow crops in the region, the individual production in alternative goods is given by $q_a^s = \bar{q}$.

Farmers have to transport their goods from the farm to the city inducing costs supposed to be linear in weight and distance. Letting t_a be the transportation cost per unit of good and distance, the profits of a farmer involved in alternative farming and located at x are:

$$\pi_a(x) = (p_a^* - t_a x)\bar{q} - R(x). \tag{5}$$

Since 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 $Q_a^s = \bar{q}\lambda_r\lambda_a$, with $0 < \lambda_a < 1$. Then, using (4) and the expression of Q_a^s, the market clearing condition for alternative goods leads to:

$$p_a^* = WTP_a - \left(\frac{1-\gamma^2}{\lambda_u}\bar{q}\lambda_r\lambda_a\right) \tag{6}$$

The term in brackets embeds both a *market size effect*, given by the inverse measure of the demand sensitivity to price ($\frac{1-\gamma^2}{\lambda_u}$) and a *supply-side competition effect* ($\bar{q}\lambda_r\lambda_a$).

Conventional food production In conventional farming, production requires farmers' labor, one unit of land, and an amount z of synthetic fertilizer. 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 $q_c^s \equiv \bar{q}F(z)$ with $F'(z) > 0$ and $F''(z) < 0$. For the ease of calculation, we further retain a Cobb-Douglas specification, so that

$$q_c^s(z) = \bar{q}\sqrt{z+1} \qquad \forall z \geq 0 \tag{7}$$

Note that when no synthetic fertilizer is used ($z = 0$), yields in conventional farming equals those of alternative farming ($q_c^s(0) = q_a^s = \bar{q}$). In this case, conventional farmers provide green goods through a conventional supply chain.

The transportation of conventional goods is divided into two segments: (i) the farm-to-elevator haulage (or procurement move) which cost is supported by each farmer and varies according to the weight and the distance to travel, and (ii) the elevator-to-user distribution borne by an intermediary. This intermediary is assumed to be located in a regional grain elevator, at the left-hand border of conventional fields $\hat{x}$. [5]. To send his production, a farmer has to pay t_c per unit of product and

[5]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.

distance covered from his farm to the elevator, and a fixed fee f_c to the intermediary. Letting p_z be the unit cost of synthetic fertilizer, the profits of a conventional farmer located at x are given by:

$$\pi_c(x) = (p_c - t_c|x - \hat{x}|)q_c^s(x) - f_c - p_z z - R(x) \tag{8}$$

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.

Conventional farmers choose their use of fertilizer so as to maximize their profit $\pi_c(x)$, leading to:

$$z^*(x) = \begin{cases} \left(\dfrac{p_c - t_c|x-\hat{x}|}{2p_z}\bar{q}\right)^2 - 1 > 0 & \text{if } \hat{x} < x \leq \tilde{x} \\ 0 & \text{if } \tilde{x} < x < \bar{x} \end{cases} \tag{9}$$

where $\tilde{x} \equiv \hat{x} + \dfrac{\bar{q}p_c - 2p_z}{\bar{q}t_c}$. The amount of synthetic fertilizer used by conventional farmers is decreasing with the distance from the regional grain elevator, meaning that the farther from the grain elevator, the less intensive the production.[6] Moreover, provided that conventional profits are positive for locations x such that $x > \tilde{x}$, the framework lets the possibility for some conventional farmers to produce green goods; these farmers still sell their production to an intermediary located at $\hat{x}$ but they do not use any synthetic fertilizer.[7] We can show that this situation occurs for a fertilizer cost high enough, that is $p_z > \frac{R_c(x)+f_c}{2}$.

The expression of $\tilde{x}$ suggests that the spatial extent of the area hosting conventional farmers who use synthetic fertilizer (further referred to as *high-input conventional farming*) only depends on exogenous parameters. This result is of particular importance as it implies that conversion to alternative farming does not systematically lead to a decrease in fertilizer use (Fig. 3.2).

A closer look at the nature of the conventional farming reveals that three cases can occur. First, all the conventional farmers produce goods using 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 that this condition can be written as $\frac{(1-\lambda_a)\lambda_r}{2}t_c < p_c - \frac{2p_z}{\bar{q}}$ or equivalently:

$$\lambda_a > \tilde{\lambda}_a \equiv 1 - \frac{2}{\lambda_r}\frac{\bar{q}p_c - 2p_z}{\bar{q}t_c}. \tag{10}$$

Second, if $\tilde{x} \leq \hat{x}$, or equivalently, if the natural ability of soils is not high enough to make the use of synthetic fertilizer economically beneficial ($\bar{q} \leq \frac{2p_z}{p_c}$), none of the conventional farmers use this

[6]See Cavailhès and Wavresky [2007] for evidences and explanations of peri-urban influences on farming systems.

[7]Organic food sold through mainstream channels are highly prevalent; in the UK for instance, but also in Scandinavian countries, over 70 to 80% of organic food is traded through conventional corporate retailers [Michelsen et al., 1999].

input[8]; in this case, the conventional farming settled in the region provides exclusively green goods. Third, if $\hat{x} < \tilde{x} < \bar{x}$ (that is, if $\bar{q} > \frac{2p_z}{p_c}$ and $\lambda_a < \tilde{\lambda}_a$), conventional farming includes both high-input and no-input farmers.

Summing up, the share of *high-input conventional farming* ($\lambda_{c|_{z>0}}$) is such:

$$\lambda_{c|_{z>0}} = \begin{cases} \dfrac{2}{(1-\lambda_a)\lambda_r} \times \dfrac{\bar{q}p_c - 2p_z}{\bar{q}t_c} & \text{if} \quad \bar{q} > \dfrac{2p_z}{p_c} \quad \text{and} \quad \lambda_a < \tilde{\lambda}_a \\ 1 & \text{if} \quad \bar{q} > \dfrac{2p_z}{p_c} \quad \text{and} \quad \tilde{\lambda}_a \leq \lambda_a < 1 \\ 0 & \text{if} \quad \bar{q} \leq \dfrac{2p_z}{p_c} \quad \text{or} \quad \lambda_a = 1 \end{cases} \tag{11}$$

This result is somewhat in line with empirical studies that focus on the factors determining the choice between conventional and environmentally-friendly practices. Pietola and Lansink [2001] for instance, find that decreasing output prices in conventional production tends to trigger the switch to organic farming, but also that conversion is more likely on farms experiencing low yields.

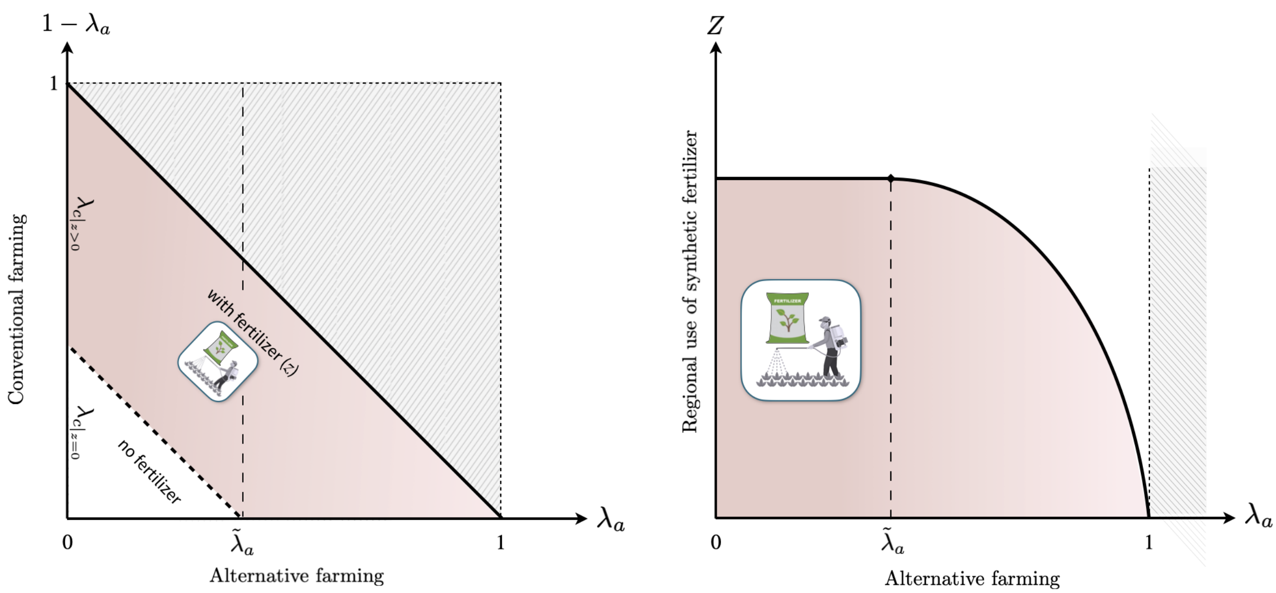

Figure 3: *Farming conversion and regional use of synthetic fertilizer*

Note finally from (11) that $\lambda_{c|_{z>0}}$ increases with the share of alternative farming (λ_a) provided that the natural ability of soils is high enough. Plugging (7) and (9) into (8), the profits for farmers involved in conventional production are finally given by:

$$\pi_c(x) = \begin{cases} \dfrac{(p_c - t_c|x-\hat{x}|)^2}{4p_z}\bar{q}^2 - f_c - R(x) + p_z & \text{if } \hat{x} < x \leq \tilde{x} \\ (p_c - t_c|x-\hat{x}|)\bar{q} - f_c - R(x) & \text{if } \tilde{x} < x < \bar{x} \end{cases} \tag{12}$$

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

2 The equilibrium pattern of agricultural land use

2.1 Equilibrium land allocation

To determine the spatial allocation of land between the urban households and the farming practices, we suppose in the manner of Von Thünen that each plot of land is allocated to the highest bidder. The equilibrium land rent is thus given by the upper envelop of bid rents, that is :

$$R^*(x) = \max\{\Psi_u(x), \Psi_a(x), \Psi_{c|_{z>0}}(x), \Psi_{c|_{z=0}}(x)\} \tag{13}$$

$\Psi_u(x)$,$\Psi_a(x)$,$\Psi_{c|_{z>0}}(x)$, $\Psi_{c|_{z=0}}(x)$ being respectively the bid land rent of urban households, alternative farmers, high-input conventional farmers and no-input conventional farmers, obtained by equating the location costs (transportation and land cost) within each area (see Appendix B.1).

Depending on the ranking of the bid rent curves, several land use configurations can occur (Fig. 4). In order to ease the discussion, we concentrate on the "*near-city*" alternative farming cases, that is when alternative farming locates in the close neighboring of the urban area (Fig. 4.A1, A2 and A3). We show in Appendix B.2 that this spatial configuration occurs if and only if the share of alternative farmers is not too high, that is, for $\lambda_a < \hat{\lambda}_a$ with $\hat{\lambda}_a = \frac{4(2p_z t_a - \bar{q}p_c t_c)}{\bar{q}t_c^2\lambda_r} > 0$[9]. In this case, the equilibrium land rent is given by:

$$R^*(x) = \begin{cases} \Psi_u^*(x) = \delta t_u|\bar{x}_u - x| + \Psi_a^*(\bar{x}_u) & \text{if } 0 < x \leq \bar{x}_u \\ \Psi_a^*(x) = t_a|\hat{x} - x|\bar{q} + \Psi_{c|_{z>0}}^*(\hat{x}) & \text{if } \bar{x}_u < x \leq \hat{x} \\ \Psi_{c|_{z>0}}^*(x) = \dfrac{p_c + t_c\left(\hat{x} - \frac{x+\tilde{x}}{2}\right)}{2p_z} t_c|\tilde{x} - x|\bar{q}^2 + \Psi_{c|_{z=0}}^*(\tilde{x}) & \text{if } \hat{x} < x \leq \tilde{x} \\ \Psi_{c|_{z=0}}^*(x) = t_c|\bar{x} - x|\bar{q} & \text{if } \tilde{x} < x < \bar{x} \end{cases} \tag{14}$$

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. 4.B).

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

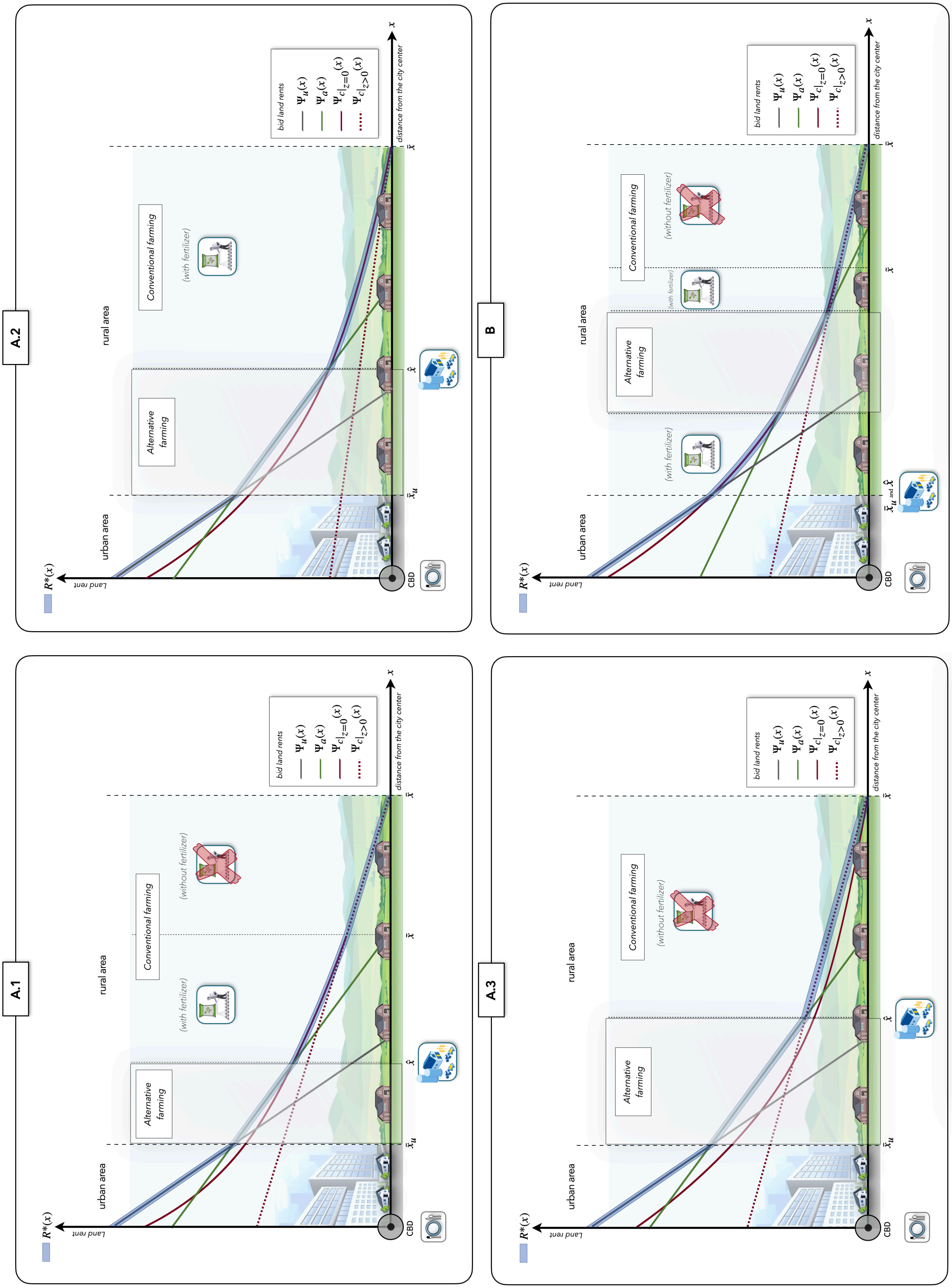

Figure 4: *Bid-rent functions and regional land allocation*

Using (14) in (5) and (12) yields the equilibrium profis in alternative and conventional farming :

$$\pi_a^* = \left[p_a^* - t_a\left(\frac{\lambda_u}{2\delta} + \frac{\lambda_a\lambda_r}{2}\right) - \frac{(\bar{q}p_c - 2p_z)^2}{4\bar{q}p_z} - \frac{(1-\lambda_a)\lambda_r}{2}t_c\right]\bar{q} \tag{15}$$

$$\pi_c^* = \left[p_c - t_c\frac{(1-\lambda_a)\lambda_r}{2}\right]\bar{q} - f_c \tag{16}$$

Recalling that the price of alternative goods decreases with respect to the share of alternative farmers (see eq.(6)), we can show that 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 is 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. Solving $\pi_c^* = \pi_a^*$ for λ_a, we derive the equilibrium share of farmers involved in alternative farming:

$$\lambda_a^* = \frac{\alpha_a - \gamma(\alpha_c - p_c) - t_a\frac{\lambda_u}{2\delta} - \left(\frac{p_z}{\bar{q}} + \frac{p_c^2\bar{q}}{4p_z}\right)}{\lambda_r\left(\bar{q}\frac{1-\gamma^2}{\lambda_u} + \frac{t_a}{2}\right)} \tag{17}$$

Since the profit differential between alternative and conventional farming decreases monotonically with respect to the share of alternative farmers, this equilibrium is unique and stable. Moreover, we define in Appendix C a range of values for t_a ensuring $0 < \lambda_a^* < 1$.

2.2 Urbanization and agricultural practices

According to (17), the share of alternative farming describes a concave function with respect to the urban population size (λ_u). This inverted U-shaped relationship 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, the larger the urban population, the stronger the market size effect. Farmers are thus encouraged to convert to alternative production so as to benefit from additional outlets. However, a larger urban population is also equivalent to a more extended residential area, resulting in higher transportation costs for farmers. Since the marginal impact of the market size effect is decreasing with the size of the urban population while that of the transportation bill is constant, there is a threshold value $\bar{\lambda}_u$ at which the equilibrium share of alternative farming achieves a maximum $\bar{\lambda}_a$.[10] Beyond $\bar{\lambda}_u$, transportation costs outweigh the market size effect so that farmers have incentives to return to conventional production.

[10] with $\bar{\lambda}_u \equiv \frac{2\bar{q}(1-\gamma^2)}{t_a}\left[\sqrt{1 + \frac{\delta}{(1-\gamma^2)\bar{q}}\left(WTP_a - \frac{4p_z^2 + p_c^2\bar{q}^2}{4\bar{q}p_z}\right)} - 1\right]$.

Proposition 2.1 *Alternative farming is more likely to develop and thrive in a region hosting an intermediate size city (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 defining the consumers preferences. First, the quality differentiation between conventional and alternative goods affects the equilibrium farming pattern as follows: the larger $\alpha_a - \alpha_c$, the higher the WTP for alternative goods, and the larger the share of alternative farming, regardless the city size. Second, as illustrated by Figure 5, the maximum alternative share $\bar{\lambda}_a$ is positively (resp. negatively) related to the degree of agricultural goods substitutability provided that the quality of the alternative good valuated by the consumers is high (resp. low). Last, agricultural goods' substitutability 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 more likely offset 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.

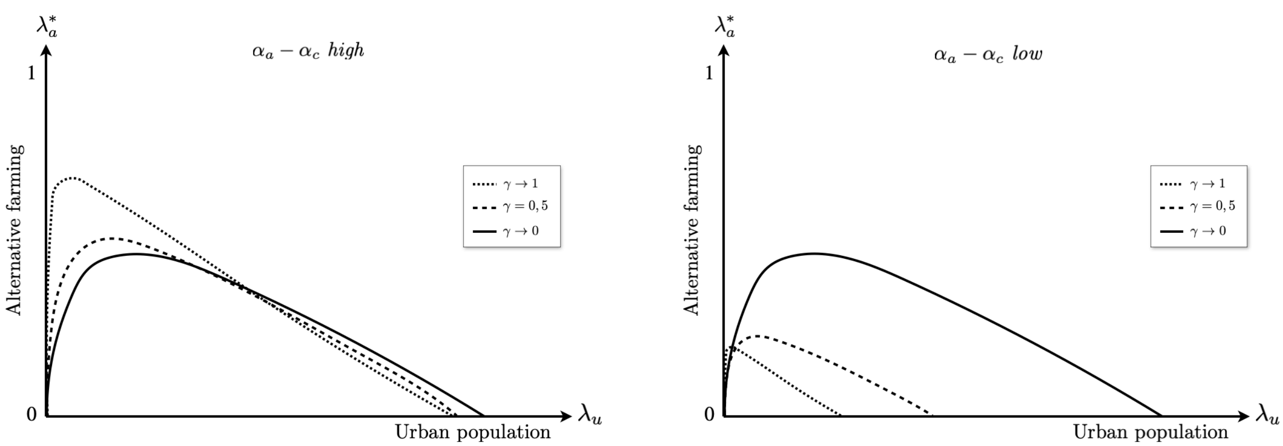

Figure 5: *Alternative farming share (λ_a^*) and urban population' size (λ_u) for different level of goods' substitutability.*

2.3 Soils quality and fertilizer use at the equilibrium

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, both the individual and the total amount of fertilizer use in conventional farming in equilibrium vary according to this characteristic (Fig. 6).

For a very low natural ability of soils, conventional farming is synthetic-free, producing only green goods. As the quality rises (while remaining below $\frac{2p_z}{p_c}$), the share of alternative farming increases; the region provides green goods from both alternative and conventional supply chains. 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 conventional production and provide mainly high-input goods.

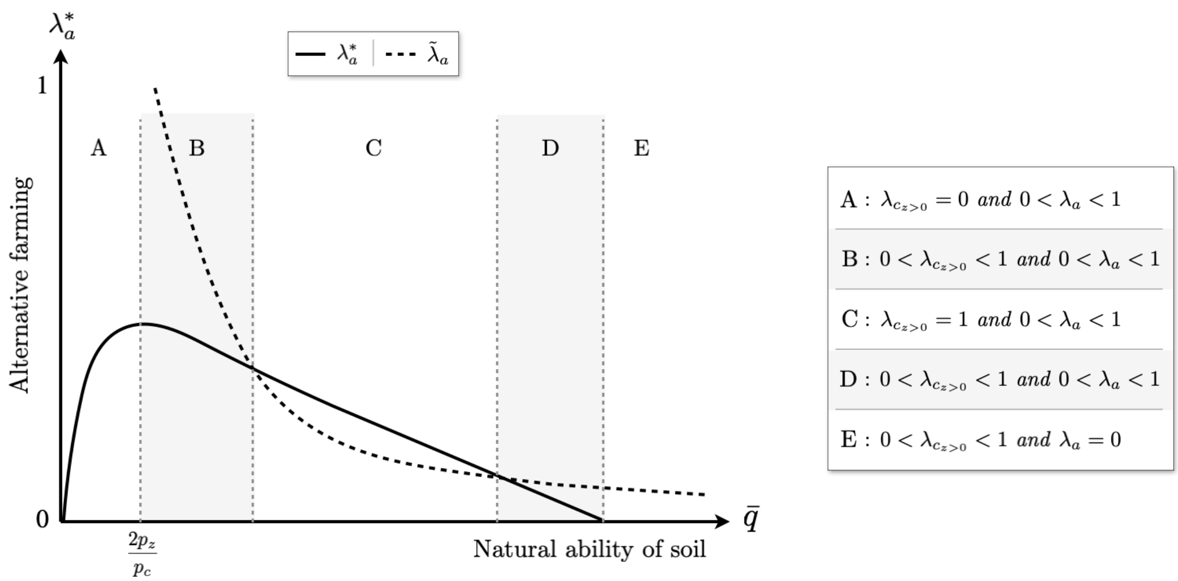

Figure 6: *The regional farming pattern at the equilibrium*

3 Agricultural pattern and regional welfare

We now address the optimality of the equilibrium farming pattern. We start by assessing the impact of alternative farming on the indirect utility of urban households. In a second step, we define the farming pattern that maximizes 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 urban household such that:

$$V_u(\lambda_a) = w_u - \frac{R^*(x)}{\delta} - t_u x + \overline{Q} + \underbrace{\left(\alpha_c - p_c - \gamma \frac{\bar{q}\lambda_a\lambda_r}{\lambda_u}\right)^2 \frac{1-\gamma^2}{2}}_{CS_c} + \underbrace{\left(\frac{\bar{q}\lambda_a\lambda_r}{\lambda_u}\right)^2 \frac{1-\gamma^2}{2}}_{CS_a} \tag{18}$$

CS_c and CS_a are the consumers surpluses evaluated at the equilibrium prices associated with the consumption of the conventional and the alternative goods, respectively. For the range of values of p_c that allows the individual demand of conventional goods q_c^d to be positive, we have $\frac{\partial CS_a}{\partial \lambda_a} > 0$, $\frac{\partial CS_c}{\partial \lambda_a} < 0$ and $\frac{\partial^2 CS_a}{\partial \lambda_a^2} > \frac{\partial^2 CS_c}{\partial \lambda_a^2}$.

Replacing $R^*(x)$ by its expression in (18) and rearranging, the indirect utility becomes:

$$V_u(\lambda_a) = A - B \times \lambda_a + C \times \lambda_a^2 \tag{19}$$

where A, B and C are constants that only depends on exogenous parameters, defined as: $A \equiv w_u - \frac{t_u \lambda_u}{2\delta} + \bar{Q} + \frac{(\alpha_c - p_c)^2(1-\gamma^2)}{2} - \left(\frac{(\bar{q}p_c - 2p_z)^2}{4\delta p_z} + \frac{\bar{q}t_c\lambda_r}{2\delta}\right)$, $B \equiv \bar{q}\lambda_r \left(\frac{t_a - t_c}{2\delta} + \frac{(\alpha_c - p_c)\gamma(1-\gamma^2)}{\lambda_u}\right) > 0$ and $C \equiv \left(\frac{\bar{q}^2(1-\gamma^4)\lambda_r^2}{2\lambda_u^2}\right) > 0$. 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.

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 (*supply-side competition effect*), leading to a larger consumers' surplus. On the other hand, alternative farming causes a rise in urban land prices; differentiating $\Psi_u^*(\bar{x}_u)$ with respect to λ_a in (14), we show that the marginal opportunity cost of urban land –*that is, the extra land cost that urban households have to pay for each additional alternative farmer*– is given by $\frac{\bar{q}(t_a - t_c)\lambda_r}{2\delta}$.

Depending on which effect outweighs the other, alternative farming can thus either improve or reduce the urban households' utility. 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, and 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 the market equilibrium by including the farmers' well-being. To this end, we define the regional social welfare function as:

$$SW(\lambda_a) = \lambda_u V_u(\lambda_a) + \lambda_a \lambda_r \pi_a^*(\lambda_a) + (1 - \lambda_a)\lambda_r \pi_c^*(\lambda_a) \tag{20}$$

with $\frac{\partial^2 SW}{\partial \lambda_a^2} < 0$.[11] Solving $\frac{\partial SW}{\partial \lambda_a} = 0$ for λ_a, we get the optimal share of alternative farming:

$$\lambda_a^o = \frac{\alpha_a - \gamma(\alpha_c - p_c)(2-\gamma^2) - t_a \frac{\lambda_u}{2\delta} - \left(\frac{p_z}{\bar{q}} + \frac{p_c^2 \bar{q}}{4p_z}\right) + t_c\left(\frac{\lambda_u}{2\delta} + \frac{\lambda_r}{2}\right)}{\lambda_r\left(\bar{q}\frac{(1-\gamma^2)^2}{\lambda_u} + t_a\right)} \tag{21}$$

Comparing (17) to (21), 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 shape of the relationship between the optimal farming pattern and the size of the urban population (λ_u)

[11] 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.

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. From (17) and (21), we get the following properties:

$$\lim_{\lambda_u \to +\infty} \lambda_a^o = -\infty \text{ and } \lim_{\lambda_u \to +\infty} \lambda_a^* = -\infty \tag{22}$$

$$\lim_{\lambda_u \to 0} \lambda_a^o = 0 \text{ and } \lim_{\lambda_u \to 0} \lambda_a^* = 0 \tag{23}$$

$$\lim_{\lambda_u \to +\infty} (\lambda_a^o - \lambda_a^*) = +\infty \tag{24}$$

$$\lim_{\lambda_u \to 0} \left(\frac{\partial \lambda_a^o}{\partial \lambda_u} - \frac{\partial \lambda_a^*}{\partial \lambda_u} \right) > 0 \tag{25}$$

We derive from (22) that the market always leads to an optimal situation for the most-urbanized regions, where no alternative farming can develop. Moreover, (23) and (25) 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 urban land is sufficiently low (see Fig.7.1). On the contrary, if this cost is high, we have previously shown that alternative farming is detrimental to the utility of large-cities dwellers. In this situation, the two curves intersect and we draw from (22)–(25) 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). [12]

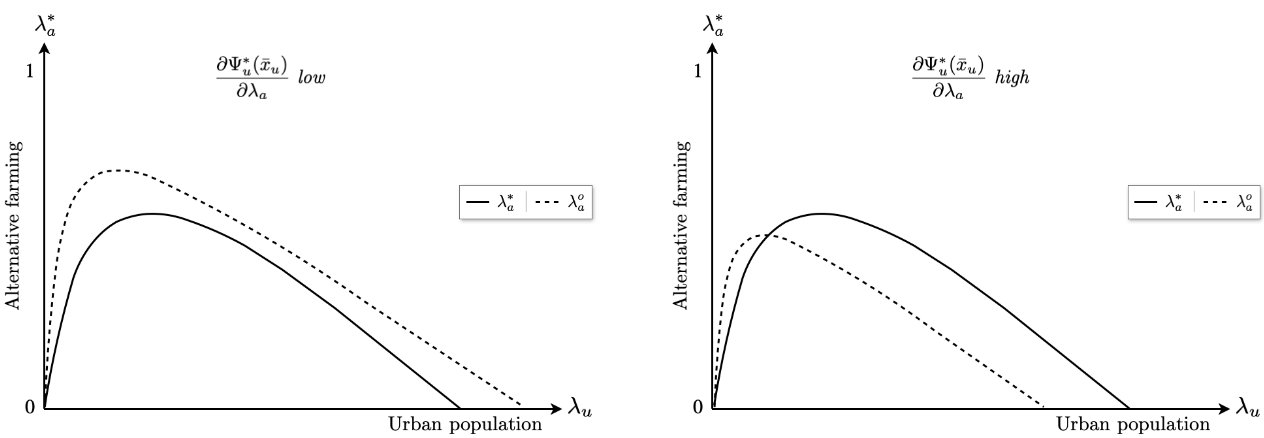

Figure 7: *Equilibrium and Optimal farming pattern in function of the urban population' size*

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 urban land remains low enough.*

[12]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 Does alternative farming development lead to reduce the urban foodprint ?

Suppose the region seeks to meet its population' needs in food whilst reducing the GHG emissions stemming from the whole supply chain. As emissions come from both production and transportation, the region faces a trade-off 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 that we consider would give the aggregate level of emissions from the whole food supply chain.

4.1 Synthetic fertilizer use and agricultural production

As previously mentioned and illustrated by Fig.(3), promoting alternative farming does not necessarily imply less fertilizer. Hence, according to the characteristics of the region, there are 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 of conventional goods in the region. Using (9), we have:

$$Z = \begin{cases} \dfrac{(\bar{q}p_c + 4p_z)(\bar{q}p_c - 2p_z)^2}{6\bar{q}p_z^2 t_c} & \text{if } \lambda_a < \tilde{\lambda}_a \\ \left[p_c^2 - \dfrac{4p_z^2}{\bar{q}^2} + \dfrac{t_c(1-\lambda_a)\lambda_r}{2}\left(\dfrac{t_c(1-\lambda_a)\lambda_r}{6} - p_c\right)\right]\dfrac{(1-\lambda_a)\lambda_r}{4p_z^2}\bar{q}^2 & \text{if } \lambda_a > \tilde{\lambda}_a \end{cases} \tag{26}$$

and

$$Q_c^s = 2\int_{\hat{x}}^{\bar{x}} q_c^{s*}(x)dx = \begin{cases} \dfrac{(\bar{q}p_c - 2p_z)^2}{2p_z t_c} + \bar{q}(1-\lambda_a)\lambda_r & \text{if } \lambda_a < \tilde{\lambda}_a \\ \dfrac{\bar{q}^2}{p_z}\left(p_c - \dfrac{t_c(1-\lambda_a)\lambda_r}{4}\right)\dfrac{(1-\lambda_a)\lambda_r}{2} & \text{if } \lambda_a > \tilde{\lambda}_a \end{cases} \tag{27}$$

As suggested by (26), 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 conventional farming produces exclusively high-input goods ($\lambda_a > \tilde{\lambda}_a$). Hence, assuming that GHG emissions are linear with the production, the emissions arising from food production are given by:

$$E_P(\lambda_a) = e_a Q_a^s + e_c Q_c^s = e_a\lambda_a\lambda_r\bar{q} + e_c\frac{\bar{q}^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2} \quad (\text{ with } \lambda_a > \tilde{\lambda}_a) \tag{28}$$

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 emissions from agricultural production decreases concavely as the share of alternative farming increases.

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 take place from $\bar{x}_u$ to $\hat{x}$, the sum of alternative freight flows within the region is given by:

$$T_a = 2\bar{q}\left(\int_{\bar{x}_u}^{\hat{x}} |x - \bar{x}_u|dx + \lambda_a\lambda_r\bar{x}_u\right) = \frac{\lambda_a\lambda_r}{2}\left(\frac{\lambda_a\lambda_r}{2} + \frac{\lambda_u}{\delta}\right)\bar{q} \tag{29}$$

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 $\hat{x}$:

$$T_c^{x\to\hat{x}} = 2\int_{\hat{x}}^{\bar{x}} q_c^{s^*}(x)|x - \hat{x}|dx = \frac{3p_c - t_c\bar{q}(1-\lambda_a)\lambda_r}{6p_z} \times \frac{\bar{q}(1-\lambda_a)^2\lambda_r^2}{4} \tag{30}$$

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

$$T_c^{\hat{x}\to CBD} = Q_c^s \hat{x} = \left[\frac{\bar{q}^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2}\right]\left(\frac{\lambda_u}{\delta} + \lambda_a\lambda_r\right) \tag{31}$$

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 final effect on intra-regional conventional transportation is 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. $T_c^{\hat{x}\to CBD}$ may by contrast 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 $|Q_c^s - Q_c^d| = \left|\int_{\hat{x}}^{\bar{x}} q_c^{s^*}(x)dx - q_c^d\lambda_u\right|$. Letting ν be the distance between the region and its trade partner, the inter-regional flow of conventional goods is such that

$$T_c^{Trade} = \begin{cases} \left[\dfrac{\bar{q}^2[4p_c - t_c(1-\lambda_a)\lambda_r](1-\lambda_a)\lambda_r}{8p_z} - \left(\alpha_c - p_c - \dfrac{\gamma\bar{q}\lambda_a\lambda_r}{\lambda_u}\right)\lambda_u\right]\nu & \text{if } \lambda_a < \lambda_a^{X|M} \\ 0 & \text{if } \lambda_a = \lambda_a^{X|M} \\ \left[\left(\alpha_c - p_c - \dfrac{\gamma\bar{q}\lambda_a\lambda_r}{\lambda_u}\right)\lambda_u - \dfrac{\bar{q}^2[4p_c - t_c(1-\lambda_a)\lambda_r](1-\lambda_a)\lambda_r}{8p_z}\right]\nu & \text{if } \lambda_a > \lambda_a^{X|M} \end{cases} \tag{32}$$

where $\lambda_a^{X|M} \equiv 1 - \frac{2\bar{q}p_c - 4\gamma p_z}{\bar{q}t_c\lambda_r} + \frac{2p_c}{t_c\lambda_r}\sqrt{\left(1 - \frac{2\gamma p_z(2p_c - t_c\lambda_r)}{\bar{q}p_c^2} + \frac{4\gamma^2 p_z^2}{\bar{q}^2 p_c^2} - \frac{2(\alpha_c - p_c)p_z t_c\lambda_u}{\bar{q}^2 p_c^2}\right)} > \tilde{\lambda}_a$ is the share of alternative farming 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 (32.1)). 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 (32.3)).

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. Using (29)–(32), the total emissions stemming from food transportation are:

$$E_T(\lambda_a) = e_{ih}[T_a(\lambda_a) + T_c^{x \to \hat{x}}(\lambda_a)] + e_{bh} T_c^{\hat{x} \to CBD}(\lambda_a) + e_t \frac{T_c^{Trade}(\lambda_a)}{2} \tag{33}$$

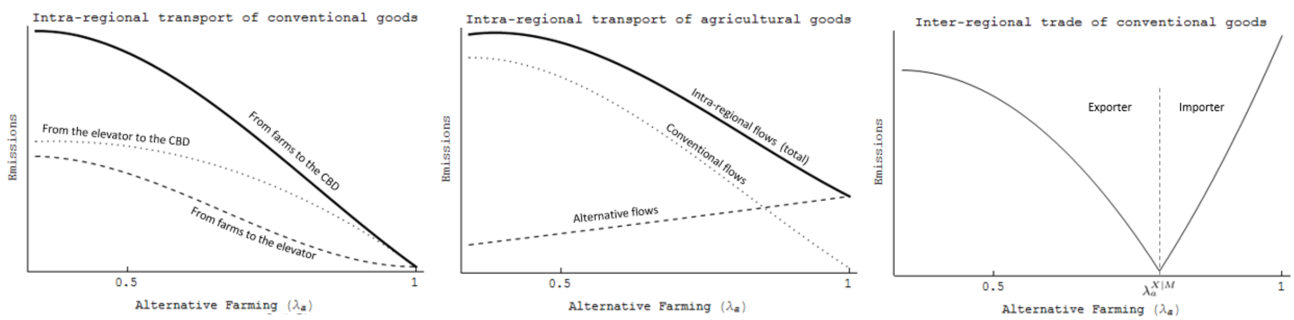

Figure 8: *GHG emissions from food transportation*

Emissions and agricultural pattern

For the sake of readability, the details for calculations have been reported in Appendix E and we only discuss its graphical representation provided in Figure 9.

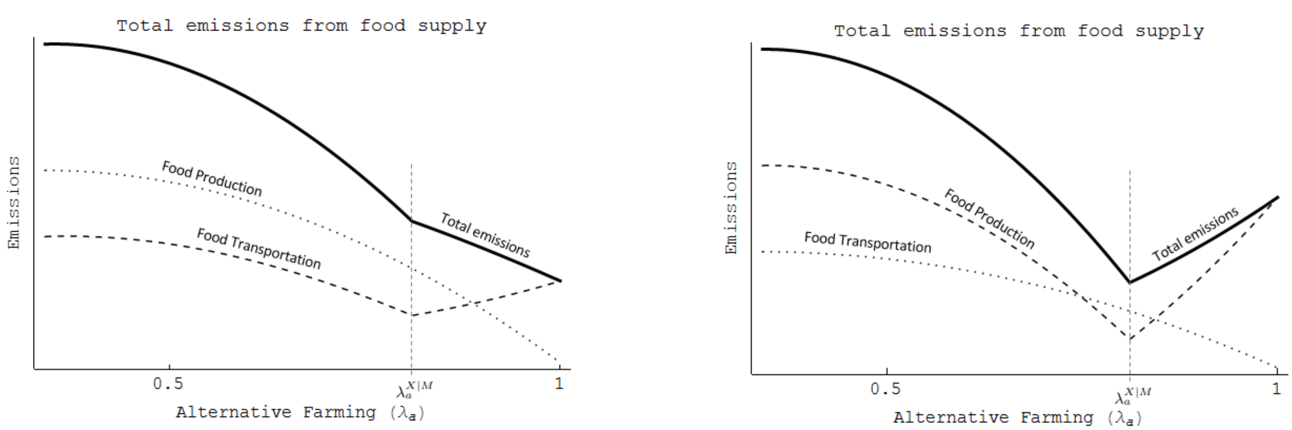

Figure 9: *Total GHG emissions from the regional food supply (urban foodprint)*

As shown 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 $\lambda_a^* < \lambda_a^o < \lambda_a^{X|M}$.

Proposition 4.1 *Starting from the equilibrium outcome, the conversion from conventional to alternative farming usually allows a cut in GHG emissions. However, in the case where emissions mainly comes from the transportation stage, the environmental benefit of conversion holds only provided that the region tends toward self-sufficiency ($\lambda_a^* \to \lambda_a^{X|M}$).*

Urbanization and emissions   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. The effect of λ_u on emissions is twofold, 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, the emissions stemming from inter-regional trade would also decrease more significantly in this region. The total effect is thus always conditional upon the relative importance of these two variations.

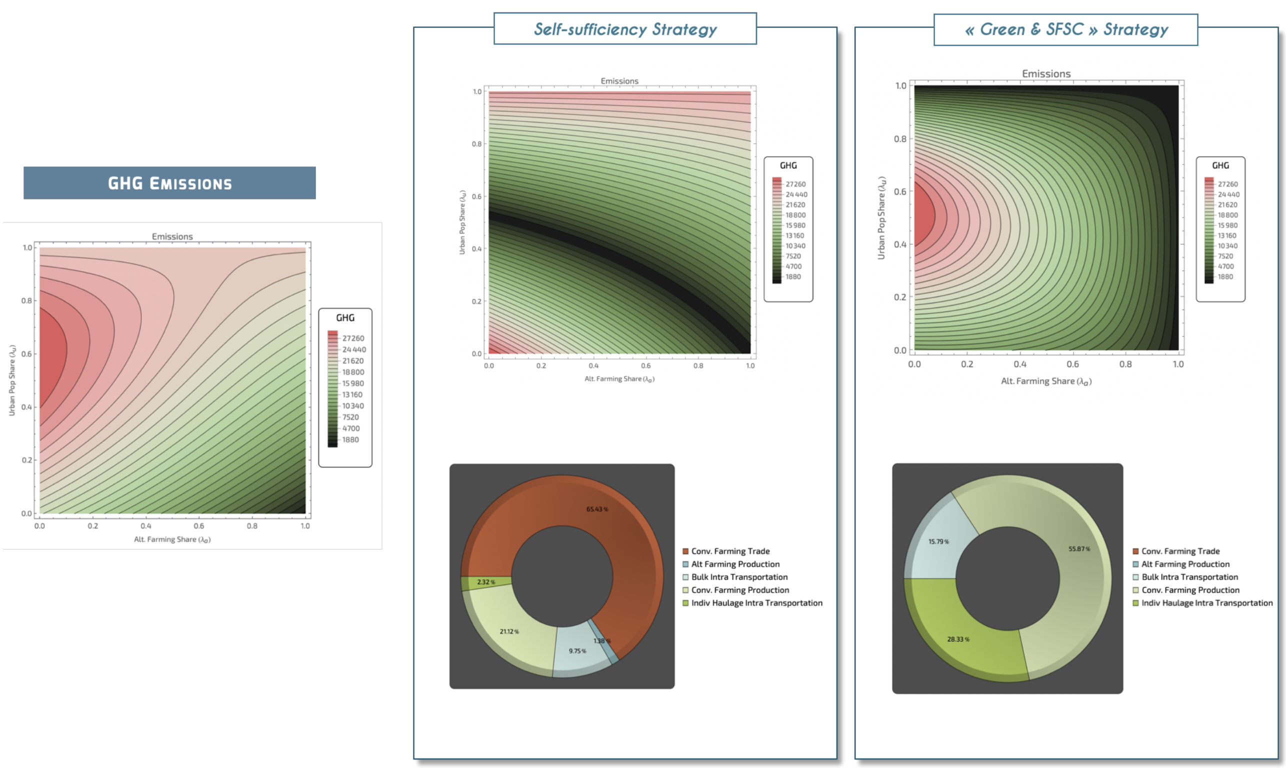

Figure 10: *Urban 'Foodprint' : numeric simulations*

Local food and emissions As for the empirical studies on the environmental impact of local food, our results clearly show that the benefits from local food are subject to conditions; when focusing on the strictly local aspect, we can see from Figure (9.1) that self-reliance does not always correspond to the lowest-emission outcome. As illustrated by the graph, promoting alternative farming development further than the share that would allow the region to be self-sufficient in food can provide additional opportunities for reducing the emissions. This supports the findings of Saunders et al. [2006] and Weber and Matthews [2008] who have underlined that distances can not be, by themselves, a suitable measure of the environmental impact of a food supply chain, especially when transportation accounts for a relatively small share of energy use and emissions in the food system; differences in types of food products as well as in production practices, natural endowments, and fertilizer use may have important implications for emissions in the food system and justifies that the "local food is best" assertion should not be generalized [Lehuger et al., 2009].

5 Assessing the impact of an energy price rising.

We finally use our model to assess 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). Moreover, 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 an agricultural transport cost rising

Suppose 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 (17), 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 rise 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 (9) 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 ($\lambda_{c|_{z=0}} \to 1$).

5.2 The impact of a fertilizer price rising

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

Assuming first that $\bar{q} > \frac{2p_z}{p_c}$, we know from (11) that farmers distribute themselves between alternative production, high-input 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. (15) and (16)) – 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. Furthermore, as producing high-input goods becomes more expensive, conventional farmers tend to diminish their use of synthetic fertilizer whatever their location (Eq. (9)). 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 high-input conventional farming $\lambda_{c|_{z>0}}$. 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. Hence, as illustrated by Figure (11), any rise of the synthetic fertilizer price would favor the conversion to alternative farming while transforming conventional farming from high-input to reduced-input practices, whereas a transportation costs increase.

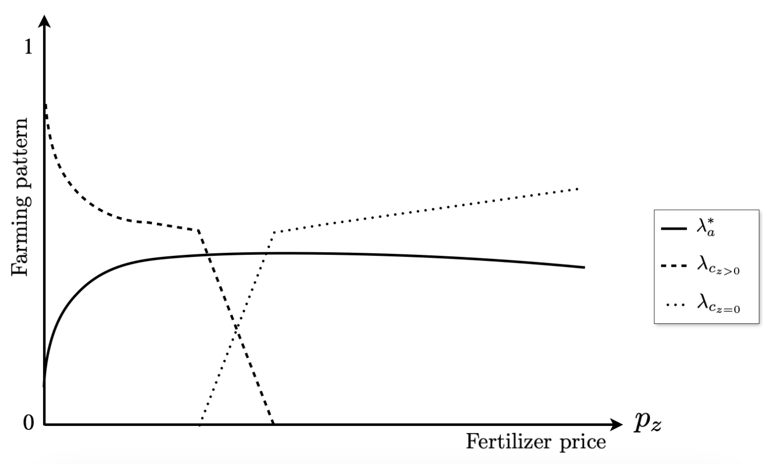

Figure 11: *The impact of a fertilizer price rising on the equilibrium farming pattern.*

Proposition 5.1 *An energy price rising always leads to diminish the share of high-input conventional farming. However, regarding the alternative farming, the impact strongly depends on the nature of the cost affected; if a rise of the synthetic fertilizer price tends to favor its development, a transportation costs increase acts, on the contrary, as a disincentive.*

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 regional 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 urban land 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 accounts for a large part in emissions may increase the 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 a rise in emissions due to trade.

The main motivation in doing this work was to go beyond the rich and wide but too heterogeneous empirical literature related to this topic, by providing a first attempt of theoretical formalization, and deriving some preliminary insight into the sustainability of alternative farming in order to better inform public policies for sustainable food supply. Although perfectible, we argue that this framework can be seen as a first step to address theoretically the issue of sustainable food supply.

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Appendix A: Fertilizer use in conventional farming

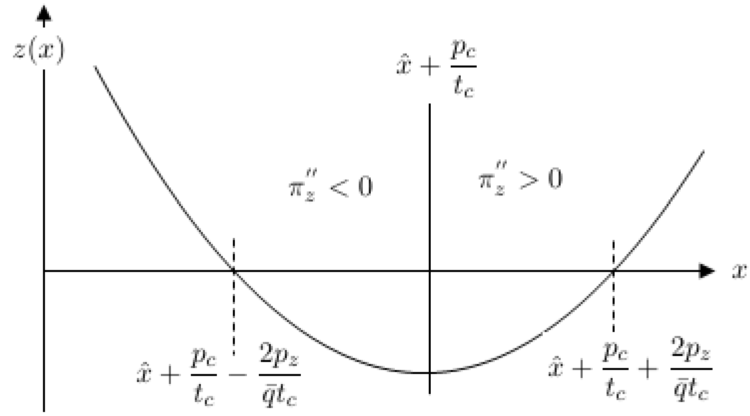

Figure 12: *Variation of synthetic fertilizer use in space*

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

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

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

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

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, $\frac{\partial R(x)}{\partial x} + \bar{q}t_a = 0$, which solution is $\Psi_a(x) = \bar{r}_a - \bar{q}t_a x$, where $\bar{r}_a$ is a constant. Assuming that $\Psi_a(x) > \Psi_{c|_{z>0}}(x)$ 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 $]\bar{x}_u, \hat{x}]$. Without loss of generality, we set the opportunity cost of land to zero, so that $\Psi_c^*(\bar{x}) = 0$. This implies that $\bar{r}_{c|_{z=0}} = \bar{q}t_c\bar{x}$.

Bid land rents of conventional farmers using synthetic fertilizer and those who do not use fertilizer must be equal at $\tilde{x}$ (i.e., $\Psi_{c|_{z>0}}(\tilde{x}) = \Psi_{c|_{z=0}}(\tilde{x})$), which yields $\bar{r}_{c|_{z>0}} = \bar{q}t_c(\bar{x} - \tilde{x}) + \frac{\bar{q}^2 t_c \tilde{x}\left[p_c - t_c\left(\frac{\tilde{x}}{2} - \hat{x}\right)\right]}{2p_z}$. In the same way, conventional alternative bid land rents must be equal at $\hat{x}$ (i.e., $\Psi_a(\hat{x}) = \Psi_{cz}(\hat{x})$), 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, $\frac{\partial R(x)}{\partial x} + \delta t_u = 0$, which solution is $\Psi_u(x) = \bar{r}_u - \delta t_u x$, $\bar{r}_u$ being a constant. At the equilibrium, urban and agricultural land rents must be equal at the city limit $\bar{x}_u$, leading to $\bar{r}_u = \delta t_u \bar{x}_u + \Psi_a(\bar{x}_u)$. As a result, the equilibrium land rent in the region is given by:

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

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 $\Psi_u^*(x)$ and $\Psi_a^*(x)$, $\Psi_u^*(x)$ and $\Psi_{c|_{z>0}}^*(x)$, and $\Psi_a^*(x)$ and $\Psi_{c|_{z>0}}^*(x)$, respectively. Since $\Psi_{c|_{z>0}}^*(x)$ is convex in 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 $\Psi_{c|_{z>0}}^*(0) < \Psi_a^*(0)$ (implying that $\Psi_a^*(x)$ and $\Psi_{c|_{z>0}}^*(x)$ intersect once) or, if the first intersection between $\Psi_a^*(x)$ and $\Psi_{c|_{z>0}}^*(x)$ occurs before the intersection between $\Psi_u^*(x)$ and $\Psi_a^*(x)$ (i.e. $x_{a|c}^1 < x_{u|a} < x_{a|c}^2$).

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

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

Appendix C: The agricultural distribution at the equilibrium

Profits in alternative and conventional farming are given by:

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

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:

$$\lambda_a^* = \frac{\alpha_a - \gamma(\alpha_c - p_c) - t_a \frac{\lambda_u}{2\delta} - \left(\frac{p_z}{\bar{q}} + \frac{p_c^2 \bar{q}}{4p_z}\right)}{\lambda_r \left(\bar{q}\frac{1-\gamma^2}{\lambda_u} + \frac{t_a}{2}\right)} \tag{34}$$

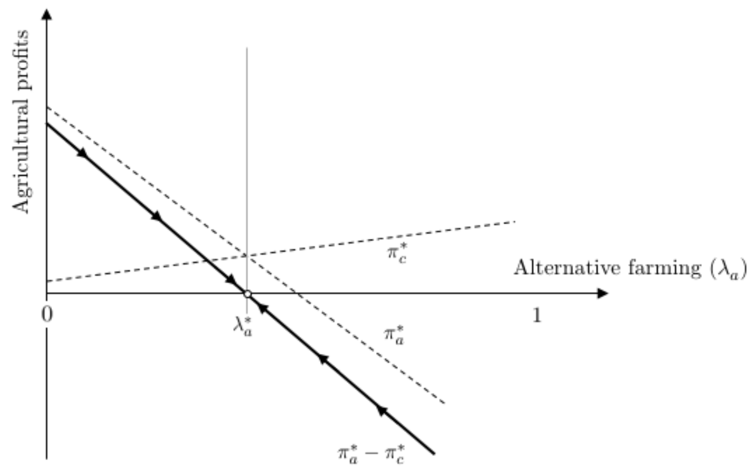

Figure 13: *Net incomes differential and equilibrium*

From (34), we derive the conditions on parameter t_a for λ_a^* to be positive and lower than 1:

$$\begin{cases} \lambda_a^* > 0 \quad \text{if} \quad t_a < \bar{t}_a \equiv \dfrac{\alpha_a - (\alpha_c - p_c)\gamma - \left(\frac{p_z}{\bar{q}} + \frac{p_c^2 \bar{q}}{4p_z}\right)}{\frac{\lambda_u}{2\delta}} \\ \lambda_a^* < 1 \quad \text{if} \quad t_a > \underline{t}_a \equiv \dfrac{\alpha_a - (\alpha_c - p_c)\gamma - \left(\frac{p_z}{\bar{q}} + \frac{p_c^2 \bar{q}}{4p_z} + \frac{\bar{q}(1-\gamma^2)\lambda_r}{\lambda_u}\right)}{\frac{\lambda_r}{2} + \frac{\lambda_u}{2\delta}} \end{cases} \tag{35}$$

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:

$$\lambda_a^o = \frac{\alpha_a - \gamma(\alpha_c - p_c)(2-\gamma^2) - t_a \frac{\lambda_u}{2\delta} - \left(\frac{p_z}{\bar{q}} + \frac{p_c^2 \bar{q}}{4p_z}\right) + t_c \left(\frac{\lambda_u}{2\delta} + \frac{\lambda_r}{2}\right)}{\lambda_r \left(\bar{q}\frac{(1-\gamma^2)^2}{\lambda_u} + t_a\right)} \tag{36}$$

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 (36) $\frac{\partial N^o}{\partial \lambda_u} < 0$, $\frac{\partial D^o}{\partial \lambda_u} > 0$, $\frac{\partial^2 N^o}{\partial \lambda_u^2} = 0$ and $\frac{\partial^2 D^o}{\partial \lambda_u^2} < 0$ so that

$$\frac{\partial^2 \lambda_a^o}{\partial \lambda_u^2} = \frac{\partial^2 D^o}{\partial \lambda_u^2} \times N^o + 2 \times \frac{\partial D^o}{\partial \lambda_u} \times \frac{\partial N^o}{\partial \lambda_u} + \frac{\partial^2 N^o}{\partial \lambda_u^2} \times D^o < 0 \tag{37}$$

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 (28) and (33), the total GHG emissions are given by:

$$\begin{aligned} E(\lambda_a) =& e_a\left(\bar{q}\lambda_a\lambda_r\right) + e_c\left[\frac{\bar{q}^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2}\right] + \\ & e_{ih}\left[\bar{q}\left(\frac{\lambda_a^2\lambda_r^2}{4} + \bar{q}\left(\frac{p_c}{2p_z} - \frac{t_c(1-\lambda_a)\lambda_r}{6p_z}\right)\frac{(1-\lambda_a)^2\lambda_r^2}{4}\right) + \frac{\lambda_u}{2\delta}\bar{q}\lambda_a\lambda_r\right] + \\ & e_{bh}\left[\frac{\bar{q}^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2}\left(\frac{\lambda_a\lambda_r}{2} + \frac{\lambda_u}{2\delta}\right)\right] + \\ & \frac{e_t}{2}\left|\frac{\bar{q}^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2} - (\alpha_c - p_c)\lambda_u + \gamma\bar{q}\lambda_a\lambda_r\right|\nu \end{aligned} \tag{38}$$

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

	T_a	$T_c^{x\rightarrow\hat{x}}$	$T_c^{\hat{x}\rightarrow CBD}$	T^{Trade}
λ_a	$\uparrow$	$\downarrow$	$\uparrow$ if $\lambda_a < \lambda_a^{\hat{x}\rightarrow CBD}$ $\downarrow$ if $\lambda_a > \lambda_a^{\hat{x}\rightarrow CBD}$	$\downarrow$ if $\lambda_a < \lambda_a^{X\|M}$ $\uparrow$ if $\lambda_a > \lambda_a^{X\|M}$
λ_a^2	+	+	-	-
λ_u	+	0	+	+
$\lambda_a\lambda_u$	+	0	-	0

Table 1: *Variations of transportation flows with respect to alternative farming share (λ_a) and urbanization (λ_u).*

with $\lambda_a^{\hat{x}\rightarrow CBD} = \frac{2}{3} + \frac{4}{3\lambda_r}\left(\sqrt{\left(\frac{p_c}{t_c} - \frac{\delta\lambda_r+\lambda_u}{4\delta}\right)^2 + \frac{p_c(\delta\lambda_r+\lambda_u)}{4t_c\delta}} - \frac{p_c}{t_c}\right)$.