Feeding the city ‘locally’ : a trade-off analysis between quality, affordability and sustainability.

Preliminary draft. Please do not quote.

Abstract

The last decades have seen a revival of short food supply chains (SFSCs) with consumers having increasingly higher expectations regarding the quality, the origin and the safety of the food. In this paper, we examine the trade-off between quality, affordability and sustainability of food products locally grown. We use a model that borrows from both spatial economic and monopolistic competition theories and allows to properly account for the urban-rural linkages. We highlight that spatial heterogeneity in productivity and land quality create distortions in competition between farmers, and can have concomitant undesired effects on the quality, the price, the ‘greenness’, and the range of available varieties. Additionally, we emphasize a nontrivial relationship between the city size and the set of food varieties which truly relies on the shape and the strength of the spatial externalities.

Keywords: Urbanization, SFSCs, Sustainability, Spatial heterogeneity, Externalities.

JEL Classification: D43; Q13; Q53; R32

1 Introduction

In many developed countries, the last decades have seen a revival of short food supply chains (SFSCs) with the development of systems where production, processing, trade and consumption occur within a particular narrowly defined geographical area. To some extent, the recent global trend in the agricultural sector can be explained by the wish of consumers to re-establish a long lasting relationship based on trust with farmers. In affluent cities in particular, consumers have increasingly higher expectations regarding the quality, the origin and the safety of the food they purchase. Food supply crises such as the BSE or the Belgian dioxin incident have caused widespread anxiety among citizens [Miles and Frewer, 2001]. In addition to concerns about safer food, a growing environmental awareness has also led consumers to question modern agricultural practices, the use of pesticides and their residues in food being perceived to be associated with long-term and unknown effects on health [Williams and Hammitt, 2001].[1]

SFSCs are not only beneficial to consumers, but also to producers. As reported by Kneafsey et al. [2013], they have become in recent years a diversification strategy increasingly used by farmers to react to the continuous price squeeze and to capture new segments of demand interested in local and fresh food. SFSCs usually enable producers to obtain a fairer share of the profit through the elimination of intermediaries, but also provide opportunities to diversify activities [Alonso, 2011]. Moreover, empirical studies conducted in the last decade greatly support the idea that, for a majority of consumers, products sold directly are perceived of a higher quality than those sold at regular grocery stores (see e.g., Dodds et al. [2014]). Hence, farmers operating on local market have a substantial leeway to bargain and add a price premium [Pearson et al., 2011], contributing in turn to improve the economic viability of rural communities [Renting et al., 2003].

Since the most-urbanized cities are hosting (on average) a wealthier population with a greater willingness-to-pay for alternative marketing channels, one may expect larger development opportunities for farming in the surrounding rural areas. This intuition seems to be partially supported by current contributions on farming development in areas under urban influence which commonly emphasize that SFSCs are more likely to meet a significant and fast-increasing new kind of demand. In this

[1]For further elements on the demand-side aspects, readers can refer to Trobe [2001] who examines the reasons why customers are increasingly attracted by direct-selling marketing.

respect, Low and Vogel [2011] notably show that "*farmers marketing food locally are most prominent in [...] areas close to densely populated urban markets*" and "*climate and topography favoring the production of fruits and vegetables, as well as good transportation and market access are found to be associated with higher levels of direct-to-consumer sales*".

However, existing research pays relatively little attention to potential negative factors that can counter-balance the attractiveness of periurban areas and, therefore, act as a brake to farming development. First, a transition towards city-wide food networks inevitably entails the question of land use and access cost. In the periphery of highly-urbanized spaces, competition for land is fiercer and tends to increase its cost, implying that low-added value activities such as agriculture can hardly thrive [Berry, 1978]. Second, besides the tensions on the land market, one can also consider environmental issues, more precisely, the detrimental effects of urban pollution on crops and land quality. As now acknowledged by extensive research, urban pollution adversely affects agricultural activity in many complex ways, causing reduced yield and quality in crops exposed to pollutants (see e.g., Adams et al. [1986]; Kuik et al. [2000]). Avnery et al. [2011] notably, estimate that reductions in global yields due to ozone exposure could be in the range 3.9-15% for wheat, and 8.5-14% for soybean.[2] Holland et al. [2006] show that the directly-induced economic consequences of urban pollution are far from being negligible, establishing the losses for Europe in 2000 to 6.7 billion euros. With these elements in mind, the environmental benefits of urban proximity can be seriously questioned.

The purpose of this paper is to investigate whether feeding cities with locally grown products necessarily relies on a tradeoff between quality, affordability and sustainability. We explore this question by developing a theoretical model with externalities on agricultural yields. We provide an environmental assessment of the agricultural activity and we show how spatial heterogeneity tends to modify the total amount of chemicals inputs used to produce local food.

Our model borrows from both spatial economic and monopolistic competition theories. We consider farming as a sector supplying urban households locally with horizontally- and vertically-differentiated goods sold under a market structure of monopolistic competition. Within this framework, the number of farmers (and, consequently, the set of varieties) can be endogenously determined as a function of the size of the urban population. Regarding the spatial aspects, our model follows the pioneering

[2] Note that in developing countries such as India and Pakistan where the ambient pollution reaches very high levels, yield loss due to ozone for sensitive crops may be 40% or more in rural areas around large cities [Marshall et al., 1997].

contributions of Von Thünen [1827] and Alonso [1964]. However, we relax the simplifying assumption that space is homogeneous in all respects except for the distance to the city center. Instead, we consider that the features of the city affect the characteristics of each location; the economy is thus modeled as a monocentric city in which market access but also urban pollution act as spatial externalities. These externalities, which depend on the size of the city and on the spread of the pollution over space, induce spatially-varying levels of land quality and productivity within the region.[3] Hence, although farmers are assumed to be homogeneous producers ex ante, having the same ability to grow crops, they may become heterogeneous ex-post because of their spatial location within the region.

As in a standard non-spatial model with monopolistic competition, we find that the profit of local farmers rises as the size of the population increases. However, when accounting for the spatial heterogeneity in land quality and productivity, the relationship becomes much more complex. We show for instance that, in highly-crowded cities, only the most productive farmers can stay on the market because of the ever fiercer competition to acquire land, with consequences on products affordability. As a result, intermediate-size cities are more likely to supply a wider range of varieties. Additionally, we stress how spatial heterogeneity in productivity levels affects our benchmark results. We highlight that, by creating distortions in competition between farmers, heterogeneity can have concomitant undesired effects on the quality, the price, the 'greenness', and the range of available varieties. We provide some preliminary findings showing that the variability of land quality over space can hinder as well as foster the production of a farmer relative to competitors, with direct consequences on the quality of the goods supplied. We thus emphasize a quality-price-variety trade-off that truly depends on spatial variations in agricultural productivity. This reinforces our previous statement that, when introducing the impact of externalities on a surrounding space, accounting for the potential heterogeneity is necessary to properly capture the implications of urban proximity on periurban development.

The paper proceeds as follows. Section 2 presents the model. In Section 3, we determine the market equilibrium, keeping the range of food varieties fixed, and we study how the relationship between price, quality and variety is affected by the externalities depending on whether they are spatially-varying (heterogeneous case) or not (homogeneous case). Section 4 presents the long-run equilibrium and

[3] Note, in this respect, that this paper can be related to the literature on international trade with monopolistic competition and heterogeneous firms which shows that heterogeneity in productivity plays an important role in explaining the structure of markets and trade flows [see e. g. Melitz [2003]; Helpman et al. [2003]; Yeaple [2005]].

provides some insights on the relationship between market entry and the city size. Section 5 offers an illustrative application of the model and Section 6 finally summarizes our conclusions.

2 The framework

Consider an economy formed by a population exogenously split into urban and rural households, and two sectors: a perfectly competitive sector, providing a homogeneous aggregate good, and an agricultural sector, providing a quality-differentiated good.

2.1 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 households are assumed to be uniformly distributed across the city and consume a plot of fixed size $\frac{1}{\delta}$ (δ capturing thus the urban density, that is, the number of urban households per unit of land). Letting λ_u be the size of the urban population, the right endpoint of the city is:

$$\bar{x}_u = \frac{\lambda_u}{2\delta}. \tag{1}$$

Farmers live and produce in areas located in the periphery of the city. Assuming that each farmer uses one unit of land to produce and denoting by λ_a the number of farmers, the right endpoint of the region is given by:

$$\bar{x} = \bar{x}_u + \frac{\lambda_a}{2} \tag{2}$$

Spatial heterogeneity : urban pollution and land quality Rural areas are exposed to urban pollution which alters the quality of land and causes yield losses that are proportional to the level of pollution encountered in each location. The land quality $q(x, \lambda_u)$ is thus supposed to be decreasing with the level of urban activities ($q_{\lambda_u} < 0$), but increasing with respect to the distance from the city center ($q(0, \lambda_u) > 0$ and $q_x > 0$).

2.2 The farming sector

Farmers produce a unique variety v using labor, one unit of land and an amount z of productivity-enhancing inputs (i.e. synthetic chemicals such as pesticides and fertilizers). We assume that each

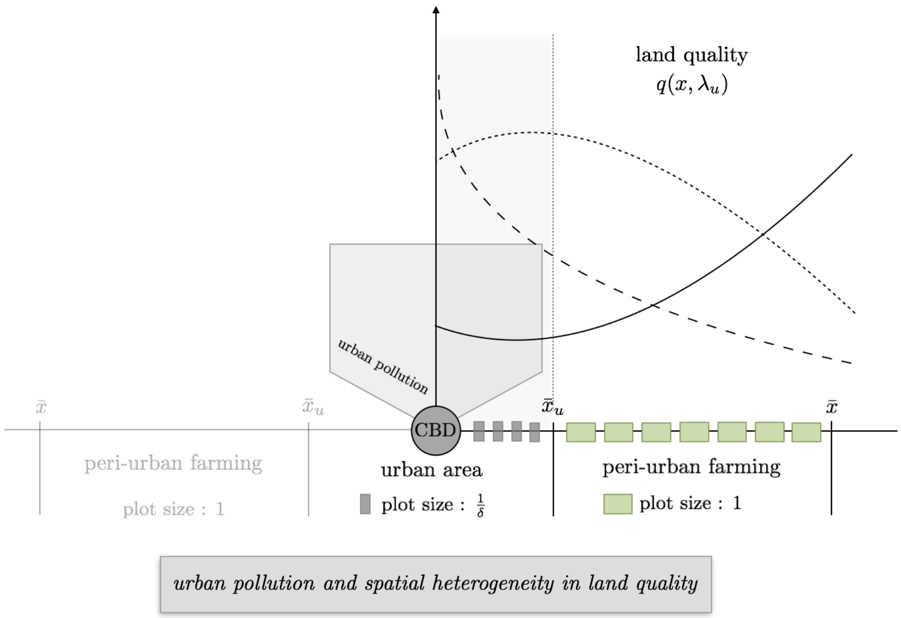

Figure 1: *Illustrative examples of spatial variations in land quality.*

variety is produced by a single farmer, implying that any variety v can equivalently be identified by the location x where it is grown.

Supply-chain and market access costs. To sell their production, peri-urban farmers have to carry it to the central market located in the city center. This incurs *market access costs* $t(x)$ that are increasing with the distance, and expressed as units of working-time required for shipping goods to the market.[4] Therefore, market access costs affect the production level through a reduction of the time spent in growing agricultural goods: the farther from the city center, the lower the time available to grow crops, and the fewer the production. This creates an incentive for farmers to locate close to the urban fringe and captures thus the opportunity cost of remoteness from the city center.

Agricultural production and externalities. The production function accounts for the effects of both market access costs and land quality on the total output. Denoting by $\bar{y}$ the natural ability of soils to grow crops in the region, and $y_v(z, x, \lambda_u)$ the quantity of the variety v produced at x, we assume:

$$y_v(z, x, \lambda_u) = \bar{y}z \times e(t(x), q(x, \lambda_u)) \tag{3}$$

[4] This specification where producers allocate their time between production and another related activity is used by Lucas and Moll [2014]. In their model, firms allocate a fraction of time to production while the remaining part is used for innovative activities.

where $0 < e(t(x), q(x, \lambda_u)) \leq 1$ stands for the agricultural productivity coefficient at x for a city size of λ_u–or similarly, $e(t(x), q(x, \lambda_u))^{-1} \geq 1$ corresponds to the *yield-loss rate*. The function e is decreasing with $t(x)$ but increasing with $q(x, \lambda_u)$.Its value is influenced by the total space-related effect of location on the production level. Formally, it encompasses the impacts of urban pollution and market access costs, that operate in opposite directions as the distance from the CBD increases. It is readily verified that differentiating $e(t(x), q(x, \lambda_u))$ with respect to x yields $e_x \equiv \frac{\partial e}{\partial t}\frac{dt}{dx} + \frac{\partial e}{\partial q}\frac{\partial q}{\partial x} = -|e_t t'(x)| + |e_q q_x|$.

In order to keep the discussion as broad as possible, we do not specify the shape of $e(t(x), q(x, \lambda_u))$. However, for the sake of tractability, we posit $e(0, 0) = 1$ meaning that, without spatial externalities, the agricultural production is given by the combination of naturel soil quality and input use. Observe finally that when externalities are invariant in space (i.e., $e(t(x), q(x, \lambda_u)) = \hat{e}(t, q(\lambda_u))\ \forall x$), peri-urban farmers operate in a spatially-homogeneous competitive environment: they experience the same productivity level $\hat{e}(t, q(\lambda_u))$ and supply the same quantity $\hat{y}$ of the same quality $\hat{\theta}$.

Rewriting (3) so as to isolate z and setting $\bar{y} = 1$ for simplicity, yields the quantity of synthetic chemicals used by the farmer located at x:

$$z(y_v, x, \lambda_u) = \frac{y_v}{e(t(x), q(x, \lambda_u))} \tag{4}$$

We easily verify from (4) that supplying a large quantity of any variety y_v always requires more inputs z. Likewise, the use of inputs z is all the more intensive that the productivity coefficient at x, $e(t(x), q(x, \lambda_u))$, is low.

The operating profit The profit of a farmer, π_v, is given by the receipts from his sales minus a total cost which consists of a fixed cost associated with the purchase of one unit of land at x, and a constant marginal cost of inputs. Letting p_v be the price of the variety v, p_z the unit cost of the inputs, and $R(x)$ land rent at x, we have:

$$\pi_v(p_v, y_v, x, \lambda_u) = p_v \times y_v - [R(x) + p_z z(y_v, x, \lambda_u)] \tag{5}$$

2.3 Preferences and demand

Consumers have a taste for variety–*in the manner described in Dixit and Stiglitz [1977]*– and are sensitive to the quality of the agricultural products.[5] In order to capture both the taste-for-variety

[5] Interested readers can refer to Abdel-Rahman [1988] or Fujita [1988] for examples of models introducing Chamberlinian monopolistic competition and taste-for-variety à la Dixit and Stiglitz [1977] into an Alonso [1964] type model

and the consumers' valuation of quality, we use the utility specification of Hallak [2006]. Consumers share the same Cobb-Douglas preferences for two types of goods; a homogeneous composite good M– *chosen as the numéraire*– and a quantity index presenting the λ_a differentiated varieties of agricultural goods Q_{λ_a}:

$$U(Q_{\lambda_a}, M) \quad = \quad \begin{cases} U(M) & \text{for } \lambda_a = 0 \\ Q_{\lambda_a}^{\alpha} M^{1-\alpha} & \text{for } \lambda_a > 0 \end{cases} \tag{6}$$

with

$$Q_{\lambda_a} = \left(\int_0^{\lambda_a} (\theta_v)^{\beta} (y_v)^{\frac{\sigma-1}{\sigma}} dv \right)^{\frac{\sigma}{\sigma-1}} \tag{7}$$

and where θ_v stands for the (perceived) quality of the variety v, $\sigma > 1$ is the elasticity of substitution between any two varieties, and β represents the preference for quality (with $0 < \beta < 1$). Utility is increasing with respect to the number of agricultural varieties λ_a and the preference for quality β.

Demand Consumers live in the urban area and work in the CBD. They earn the same income w_u and bear *urban costs*, given by the sum of the commuting costs and the housing cost. Denoting by t_u the unit commuting cost and recalling that $R(x)$ is the land rent at x, we define the *urban net income* as:

$$\zeta_u(x) \equiv w_u - \left(t_u x + \frac{R(x)}{\delta} \right) \tag{8}$$

We show in Appendix A that, at the residential equilibrium, the urban net income $\zeta_u(x)$ is invariant in space so that, $\zeta_u(x) = \zeta_u \ \forall x$. The expenditures on the composite good and the aggregate of agricultural goods are derived from the maximization of the utility (6) subject to the (binding) budget constraint $P_a Q_{\lambda_a} + M = \zeta_u$:

$$M = (1-\alpha)\zeta_u \quad \text{and} \quad Q_{\lambda_a} = \frac{\alpha \zeta_u}{P_a} \tag{9}$$

where P_a is the price index for the range of agricultural varieties locally supplied.

We establish from (9) that expenditures on aggregate of agricultural goods are $\alpha\zeta_u$; the (binding) budget constraint for agricultural goods consumption is thus given by $\alpha\zeta_u = \int_0^{\lambda_a} p_v y_v dv$. Maximizing the sub-utility (7) subject to this constraint leads to the following demand function for any variety v:

$$y_v = (\theta_v)^{\sigma\beta} (p_v)^{-\sigma} P_a^{\sigma-1} \alpha \zeta_u \lambda_u \tag{10}$$

featuring a continuous location-space.

with the (quality-adjusted) price index for agricultural goods

$$P_a = \left(\int_0^{\lambda_a} (\theta_v)^{\sigma\beta} (p_v)^{1-\sigma} dv \right)^{\frac{1}{1-\sigma}} \tag{11}$$

Goods quality Agricultural goods differ in quality θ_v. This quality, as perceived by the consumers, is assumed to be linked to the quantity of synthetic chemicals used in the production as follows:

$$\theta_v = \frac{\bar{\theta}}{z(y_v, x, \lambda_u)} \tag{12}$$

$\bar{\theta}$ being the maximum quality level.

Observe that, here, quality rather refers to consumers perception than to real organoleptic properties. In other words, we suppose that consumers are aware of the quantity of synthetic chemicals used for each variety and that they are reluctant to purchase goods grown with a large amount of these inputs.[6]

Plugging (4) into (12), using the resulting expression of θ_v in (10), and solving for y_v yields:

$$y_v(p_v, x, \lambda_u) = \left(\left[\bar{\theta} e(t(x), q(x, \lambda_u))\right]^{\frac{\sigma\beta}{\sigma-1}} p_v^{-\frac{\sigma}{\sigma-1}} (\alpha\zeta_u\lambda_u)^{\frac{1}{\sigma-1}} P_a \right)^{\eta} \tag{13}$$

where $\eta \equiv \frac{\sigma-1}{1+\sigma\beta}$ is the elasticity of demand with respect to the agricultural price index, that is, the impact of a marginal increase in P_a on the demand for any variety v.

2.4 The market structure

Farmers operate on a local market under monopolistic competition; in contrast with conventional farming, they can set their own price both because they sell differentiated products and they do not interact with any intermediary. They supply close substitutes and are free to enter or exit the market.

Pricing Each farmer sets his price so as to maximize his profit and taking the price index P_a as a constant. Plugging (13) into (5) and equating the first derivative of $\pi_v(p_v, x, \lambda_u)$ with respect to p_v to zero yields the equilibrium price of the variety v produced at x:[7]

$$p^m(x, \lambda_u) = \frac{\sigma}{\sigma(1-\beta)-1} \left(\frac{p_z}{e(t(x), q(x, \lambda_u))} \right) \tag{14}$$

[6]Evidences on the link between food quality, safety, and the willingness-to-pay for synthetic-free products can be found in Grunert [2005] or Marette et al. [2012].

[7]Note that, $\pi_v(p_v, x, \lambda_u)$ is concave in p_v for $p < \frac{p_z}{e(t(x),q(x,\lambda_u))} \frac{\sigma+(1+\sigma\beta)}{\sigma-(1+\sigma\beta)}$, a condition verified at the equilibrium price.

where m labels equilibrium variables and $\sigma > \frac{1}{1-\beta}$ must hold for $p^m(x, \lambda_u)$ to be positive. Note that to lighten the expressions, we now drop the index v, each variety being identified by the (unique) location x where it is grown.

The first element of (14) is the monopolistic mark-up. It is always greater than 1 and increases with the quality elasticity of the demand $\sigma\beta$, reflecting the fact that farmers are fully aware that consumers are concerned by the quality of their product. The term in parentheses represents the marginal cost of production for the variety grown at x. It increases with the unit cost of the input p_z, but also with the yield-loss rate, meaning that farmers partially pass on the charge of heterogeneity in land quality and market access costs to consumers.

Market share and competition Using Eqs (4) and (11)–(14) to calculate the price index P_a and re-injecting its value in (13) gives the demand for any agricultural variety y as a function of x, λ_u and λ_a. Multiplying this expression of $y(x, \lambda_u, \lambda_a)$ by $p^m(x, \lambda_u)$, we obtain the receipts of the farmer located at x:

$$r(x, \lambda_u, \lambda_a) \equiv y(x, \lambda_u, \lambda_a) \times p^m(x, \lambda_u) = \frac{\alpha\zeta_u\lambda_u}{S(\lambda_u, \lambda_a)} e(t(x), q(x, \lambda_u))^\eta \tag{15}$$

where $S(\lambda_u, \lambda_a) \equiv 2\int_{\bar{x}_u}^{\bar{x}} e(t(x), q(x, \lambda_u))^\eta dx$ captures the *supply-side market potential* of local food production: The higher $S(\lambda_u, \lambda_a)$, the greater the possibility for local farming to produce large quantities of any variety (*intensive margin*) or, alternatively, a large range of varieties (*extensive margin*). Besides, we show in Appendix B that $S(\lambda_u, \lambda_a)$ is decreasing with λ_u; for any larger city, urban pollution and market access costs are higher, inducing lower levels of productivity coefficient at each location x, and thereby, a lower market potential. Hence, in our model, urbanization makes the production in the neighboring farmland more costly. This fact adequately reproduces the empirical evidence that agriculture tends to disappear near large cities.

We finally derive from (15) the market share s of the farmer located at x:

$$s(x, \lambda_u, \lambda_a) \equiv \frac{r(x, \lambda_u, \lambda_a)}{2\int_{\bar{x}_u}^{\bar{x}} r(x, \lambda_u, \lambda_a) dx} = \frac{e(t(x), q(x, \lambda_u))^\eta}{S(\lambda_u, \lambda_a)} \qquad (0 < s(x, \lambda_u, \lambda_a) \leq 1) \tag{16}$$

As readily shown from (15), the numerator $e(t(x), q(x, \lambda_u))^\eta$ corresponds to the location-dependent part of the receipts. Hence, the larger the productivity coefficient at x, the higher the market share of the farmer producing at this location. Still in Appendix B, we establish the following properties:

1. The spatial variation of the market share follows that of $e(t(x), q(x, \lambda_u))$ and when productivity is homogeneous over space ($e(t(x), q(x, \lambda_u)) = \hat{e}(t, q(\lambda_u)) \ \forall \ x$), farmers have the same market share given by $\hat{s} = \frac{1}{\lambda_a}$.
2. The market share is always decreasing with the number of competitors λ_a and the larger the share of the farmer located at x, the greater his loss in market share.
3. The market share is increasing with the urban population for the most productive farmers, but decreasing for farmers experiencing low productivity levels.

Observe that the last property only holds when externalities vary over space. Indeed, under space-invariant externalities, urban pollution affects every location in the same extent, and has consequently no impact on market shares. More importantly, this emphasizes that introducing externalities in our model brings different consequences, depending on whether they are or not varying over space. In particular, it is clear that *spatial heterogeneity creates distortion in competition between farmers and is thus more likely to modify the conditions to enter the local market.*

3 Agricultural market equilibrium and goods quality.

3.1 Spatial location and land market equilibrium

To determine the spatial allocation of land between urban households and farmers, we suppose in the manner of Von Thünen [1827] 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:

$$R^m(x) = \max\{\varphi_u(x), \varphi_a(x), \bar{R}\} \tag{17}$$

$\varphi_u(x)$, $\varphi_a(x)$, and $\bar{R}$ being the bid land rent of urban households, farmers, and opportunity cost of land, respectively. For the ease of reading, the details of the resolution are reported in Appendix A. As shown therein, the equilibrium land rent is given by:

$$R^m(x, \lambda_u, \lambda_a) = \begin{cases} \delta\left(w_u - \zeta_u^m(\lambda_u, \lambda_a) - t_u x\right) & \text{if } 0 < x \leq \bar{x}_u \ \textit{(urban area)} \\ \alpha\psi\lambda_u\zeta_u^m(\lambda_u, \lambda_a)\dfrac{e(t(x), q(x, \lambda_u))^\eta - \bar{e}^\eta}{S(\lambda_u, \lambda_a)} + \bar{R} & \text{if } \bar{x}_u < x \leq \bar{x} \ \textit{(periurban farming area)} \\ \bar{R} & \text{if } x > \bar{x} \ \textit{(natural area)} \end{cases} \tag{18}$$

where $\psi \equiv \frac{1+\sigma\beta}{\sigma}$ is the *Lerner index* ($0 < \psi < 1$), $\zeta_u^m(\lambda_u, \lambda_a)$ is the urban net income at the land market equilibrium:

$$\zeta_u^m(\lambda_u, \lambda_a) \equiv \frac{w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}}{\frac{\alpha\psi\lambda_u}{\delta} \frac{\bar{e}_u^\eta - \bar{e}^\eta}{S(\lambda_u, \lambda_a)} + 1} \tag{19}$$

and $\bar{e}_u$ and $\bar{e}$ stand respectively for the productivity coefficient at each edge of the periurban area (i.e., $e(t(\bar{x}_u), q(\bar{x}_u, \lambda_u)$ and $e(t(\bar{x}), q(\bar{x}, \lambda_u))$.[8] The positivity of ζ_u^m implies that $\lambda_u < 2\left(\frac{\delta w_u - \bar{R}}{t_u}\right)$, a condition assumed to hold in the following. The denominator of (19) captures the effects of spatial heterogeneity. It corresponds to a measure of the competition intensity on the land market at the urban fringe; the more the farmers can outbid, the larger the denominator, and the smaller the net income. Interestingly, we can observe that when the productivity is homogeneous over space, the competition to acquire land at the urban fringe is at its lowest level. Indeed, in this case, the denominator equals to one–*so that we recover the standard expression for the equilibrium net income in bid-rent models, given by* $(w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta})$– and the cost of land falls to $\bar{R}$ for every rural location, that is for all the locations $x > \bar{x}_u$.

3.2 Competition, goods quality and environmental impact

Using Eqs (15) and (18)–(19) in (5) and rearranging, yields the market equilibrium profit:

$$\pi^m(\lambda_u, \lambda_a) = \frac{\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R}}{\bar{e}_u^\eta - \bar{e}^\eta + \frac{\delta S(\lambda_u, \lambda_a)}{\alpha\psi\lambda_u}} \times \bar{e}^\eta - \bar{R} \tag{20}$$

We show in Appendix C that π^m is decreasing with the number of farmers λ_a.

Similarly, we can calculate the quality and the quantity of the variety produced at x, evaluated at the market equilibrium:

$$\theta^m(x, \lambda_u, \lambda_a) = \frac{\frac{\bar{\theta} p_z(1+\sigma\beta)}{\sigma(1-\beta)-1} \left[\frac{\bar{e}_u^\eta - \bar{e}^\eta + \frac{\delta S(\lambda_u, \lambda_a)}{\alpha\psi\lambda_u}}{e(t(x), q(x, \lambda_u))^\eta}\right]}{\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R}} \quad \text{and} \quad y^m(x, \lambda_u, \lambda_a) = \frac{\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R}}{\frac{p_z(1+\sigma\beta)}{\sigma(1-\beta)-1} \left[\frac{\bar{e}_u^\eta - \bar{e}^\eta + \frac{\delta S(\lambda_u, \lambda_a)}{\alpha\psi\lambda_u}}{e(t(x), q(x, \lambda_u))^{\eta+1}}\right]} \tag{21}$$

The terms in square brackets embed all the effects stemming from the introduction of spatial externalities. $y^m(x, \lambda_u, \lambda_a)$ and $\theta^m(x, \lambda_u, \lambda_a)$ vary in opposite direction with respect to the productivity level $e(t(x), q(x, \lambda_u))$; letting x_a and x_b be two locations such that $\{x_a, x_b\} \in [\bar{x}_u; \bar{x}]$, we can state that the production (resp. the quality) at x_a is greater (resp. lower) than the production (resp. the quality) at x_b provided that the agricultural productivity coefficient at x_a is higher

[8] In our model, ψ represents the bargaining power of farmers relative to the consumers.

than at x_b (i.e. $y^m(x_a, \lambda_u, \lambda_a) > y^m(x_b, \lambda_u, \lambda_a)$ and $\theta^m(x_a, \lambda_u, \lambda_a) < \theta^m(x_b, \lambda_u, \lambda_a)$ provided that $e(t(x_a), q(x_a, \lambda_u)) > e(t(x_b), q(x_b, \lambda_u)))$.

The implication in terms of goods quality may be counter-intuitive. Indeed, since the use of chemicals inputs z is decreasing with respect to $e(t(x), q(x, \lambda_u))$, we may have expected that the quality would be lower for the varieties grown on locations displaying low-productivity levels. The explanation lies in the relationship between productivity, demand and market share. By definition, a farmer with a high market share has to supply a large quantity of goods, giving an incentive to use more input so as to meet the demand, but resulting, in the same time, in a loss of quality.

Regarding the features of the competition on the local market, we find that the quality of any variety is improving with the gap in productivity $(\bar{e}_u - \bar{e})$. As shown by (19), an increase in $(\bar{e}_u - \bar{e})$ induces a loss in urban net income, due to a fiercer competition on the land market. The demand for local goods is consequently lower, contributing in turn to an increase in quality.

Lastly, the quality can also be improved by an increase in the market potential $S(\lambda_a, \lambda_u)$. This can either come from a larger number of agricultural varieties λ_a, leading to a more competitive market and a fragmentation of the consumer demand, or from an enhancement in the productivity coefficient levels $e(t(x), q(x, \lambda_u))$, resulting in a decrease in fertilizer use.

We finally define the environmental impact of local farming as the total amount of chemicals inputs z used to produce food in the periurban area:

$$EI(\lambda_u, \lambda_a) \equiv \int_{\bar{x}_u}^{\bar{x}} z(y_v, x, \lambda_u)dx = \frac{\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R}}{\frac{p_z(1+\sigma\beta)}{\sigma(1-\beta)-1}\left[\bar{s}_u - \bar{s} + \frac{\delta}{\alpha\psi\lambda_u}\right]} \tag{22}$$

with the simplifying notations $\bar{s}_u \equiv s(\bar{x}_u, \lambda_u, \lambda_a)$ and $\bar{s} \equiv s(\bar{x}, \lambda_u, \lambda_a)$.

Note also that $EI(\lambda_u, \lambda_a)$ is decreasing with the inputs costs p_z which suggests that taxation on chemicals inputs can be used as a public policy tool to enhance the environmental impact of local agriculture.

Quality, variety and heterogeneity in productivity Table 1 offers a condensed overview of our results by summarizing the impact of the externalities on the net income, the quality, the quantity and the 'greenness' of the local agricultural production. More precisely, it allows to emphasize the fact that, more than the presence or not of externalities, what truly matters is their variations over space. As readily verified from the table, the space-invariant case has more in common with the scenario without externality than with the spatially-varying case.

	No externality	With externalities	
		space-invariant (homogeneous case)	spatially-varying (heterogeneous case)
	$e(t(x), q(x, \lambda_u)) = 1 \ \forall \ x$	$e(t(x), q(x, \lambda_u)) = \hat{e}(t, q(\lambda_u)) \ \forall \ x$	$e(t(x), q(x, \lambda_u))$
Urban net income (ζ_u^m)	$w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}$	$w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}$	$\frac{w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}}{\frac{\alpha\psi\lambda_u}{\delta}(\bar{s}_u - \bar{s}) + 1}$
Goods quality (θ^m)	$\frac{\frac{\bar{\theta} p_z (1+\sigma\beta)}{\sigma(1-\beta)-1} \lambda_a}{\alpha\psi\lambda_u \left(w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}\right)}$	$\frac{\frac{\bar{\theta} p_z (1+\sigma\beta)}{\sigma(1-\beta)-1} \lambda_a}{\alpha\psi\lambda_u \left(w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}\right)}$	$\frac{\frac{\bar{\theta} p_z (1+\sigma\beta)}{\sigma(1-\beta)-1} \left[\frac{\bar{e}_u^{\eta} - \bar{e}^{\eta} + \frac{\delta S(\lambda_u, \lambda_a)}{\alpha\psi\lambda_u}}{e(t(x), q(x, \lambda_u))^{\eta}}\right]}{\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R}}$
Goods quantity (y^m)	$\frac{\alpha\psi\lambda_u \left(w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}\right)}{\frac{p_z (1+\sigma\beta)}{\sigma(1-\beta)-1} \lambda_a}$	$\frac{\alpha\psi\lambda_u \left(w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}\right)}{\frac{p_z (1+\sigma\beta)}{\sigma(1-\beta)-1} \lambda_a} \hat{e}(t, q(\lambda_u))$	$\frac{\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R}}{\frac{p_z (1+\sigma\beta)}{\sigma(1-\beta)-1} \left[\frac{\bar{e}_u^{\eta} - \bar{e}^{\eta} + \frac{\delta S(\lambda_u, \lambda_a)}{\alpha\psi\lambda_u}}{e(t(x), q(x, \lambda_u))^{\eta+1}}\right]}$
Environmental Impact (EI)	$\frac{\alpha\psi\lambda_u \left(w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}\right)}{\frac{p_z (1+\sigma\beta)}{\sigma(1-\beta)-1}}$	$\frac{\alpha\psi\lambda_u \left(w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}\right)}{\frac{p_z (1+\sigma\beta)}{\sigma(1-\beta)-1}}$	$\frac{\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R}}{\frac{p_z (1+\sigma\beta)}{\sigma(1-\beta)-1} \left[\bar{s}_u - \bar{s} + \frac{\delta}{\alpha\psi\lambda_u}\right]}$

Table 1: *Urban net income, quality, quantity and 'greenness' under a) no externality, b) space-invariant externalities, and c) spatially-varying externalities.*

Table 1 also enables to shed light on a quantity–quality–variety trade-off. When externalities do not vary in space for instance, it clearly appears that quality is increasing with the range of agricultural goods. Besides, observe that an increase in urban pollution would have different consequences depending on whether externalities are space-invariant or not. Under homogeneous productivity, farmers have the same market share, implying that the bid land rent for periurban farming is flat. As the externalities do not impact the land market outcome, the urban net income and thereby the quality are not affected by the level of urban pollution. Nonetheless, as the production becomes more costly because of a decrease in land quality, farmers reduce their supply which entails a price increase.

This result does not hold when externalities are spatially-varying. The heterogeneity in productivity now introduces distortions in competition between peri-urban farmers. Depending on their location, they are unevenly affected by the losses in land quality and do not provide the same quantity of goods. Hence, although the productivity coefficients decline for all the locations, restricting the technical possibility to grow crops, farmers enjoying better land can more easily cope with it. The quantity supplied by the least-productive farmers decreases, losing in the same time market share in favor of the most-productive ones. In the end, the market consists in some significant producers who supply large quantities of low-quality goods and other small producers, offering better-quality goods but in (very) low quantity *–or equivalently, at (very) high price.*

More generally, we derive the following proposition:

Proposition 3.1 *Increasing the level of urban pollution affects the quality and the quantity of agricultural goods in different ways depending whether externalities are varying over space or not.*

This proposition raises an essential question regarding the adequate range of agricultural varieties in the periurban area. So far, the number of farmers was supposed fixed. However, under increasing competitive pressure, farmers may be forced to exit the market for lack of sufficient operating profit, the range of varieties becoming consequently narrower. We propose to investigate this point in the next section by relaxing the assumption of exogenous number of varieties.

4 The free-entry equilibrium.

We now allow for free entry and exit. In our framework, the market converges to the equilibrium according to the following mechanism: the entrance of a new competitor in the agricultural market drives the profits down while entailing a decrease in the periurban bid rent, which tends to smooth over space (as illustrated by Figure(2)). Farmers keep entering the market as long as the profit they can earn stays positive.

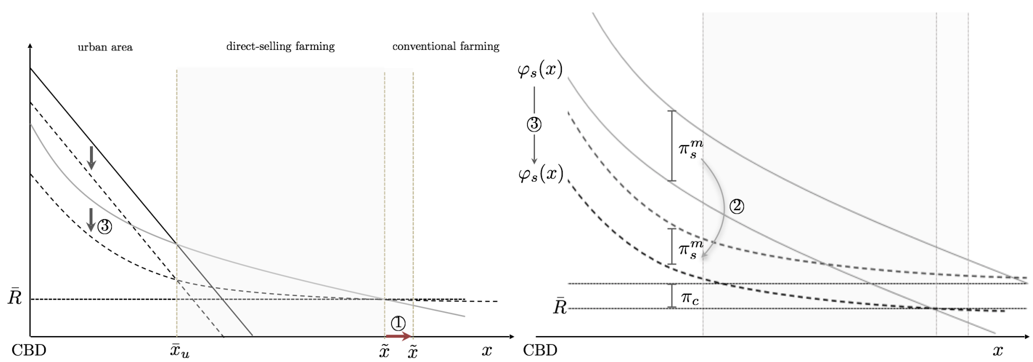

Figure 2: *Farmers entrance, land allocation and profits. In this example, the entrance of an additional farmer in the sector is illustrated by the displacement of the periurban fringe $\bar{x}$. This entails a decrease in profit π^m and, as a consequence, a decrease in the bid land rent of farmers $\varphi_a(x)$.*

4.1 The equilibrium number of agricultural varieties.

Since the profit π^m is decreasing with the number of farmers λ_a involved in the market, the long-run equilibrium is ensured to be a unique stable interior solution. Let assume a zero profit condition.

Then, solving $\pi^m(\lambda_u, \lambda_a) = 0$, the number of agricultural varieties at the free-entry equilibrium λ_a^* must verify:[9]

$$\frac{\alpha\psi\lambda_u}{\delta} = \frac{S(\lambda_u, \lambda_a)}{\left(\frac{\delta w_u - \frac{t_u \lambda_u}{2}}{\bar{R}}\right)\bar{e}^{\eta} - \bar{e}_u^{\eta}} \tag{23}$$

The LHS of (23) stands for the *demand-side market effect*. It is increasing with the urban population size λ_u and the Lerner index ψ, and plays as a Home Market Effect (HME); as the size of the urban population rises, the incentive to enter the local market increases. The RHS captures the *supply-side competition effect* and is increasing with the number of farmers. The term $(\delta w_u - \frac{t_u \lambda_u}{2})$ represents the highest potential bid of the urban households on the land market at the urban fringe. It corresponds to the price of land that would completely absorb their net income. Reported on the opportunity cost of land $\bar{R}$, the ratio measures the power of urban households on the land market relative to the farmers. The larger $(\frac{\delta w_u - \frac{t_u \lambda_u}{2}}{\bar{R}})$, the wealthier the households and the greater the opportunities for farmers to enter the market. Observe finally that the existence of this equilibrium is ensured only provided that the difference in productivity between the farmers located at the periurban boundaries $\bar{x}_u$ and $\bar{x}$ is not too large, that is $1 > \frac{\bar{e}}{\bar{e}_u} > \left(\frac{\bar{R}}{\delta w_u - \frac{t_u \lambda_u}{2}}\right)^{\frac{1}{\eta}} > 0$.

Using the equilibrium condition (23), we can calculate the quantity and the quality of local goods at the free-entry equilibrium. These values are provided below.

Interestingly, Table 2 highlights that, compared to the homogeneous case, *the urban net income and the quality of local goods are always lower under heterogeneous productivity, while the quantity of some varieties can be larger.*

4.2 Local farming and the city size.

The relationship between the urban population size and the range of agricultural varieties is not trivial as it jointly affects the supply and the demand sides of the market. On the one hand, a highly-crowded city gives an incentive for farmers to enter the market since they would benefit from a large demand. On the other hand, the city size influences the level of the spatial externalities, playing on both the pollution intensity and the market access cost, and inducing variations in land quality and productivity over space. Moreover, the inclusion of the land market brings additional spillover effects related to

[9]Note that (23) can alternatively be written as $\bar{s} = \left(\bar{R} \times \frac{\bar{s}_u + \frac{\delta}{\alpha\psi\lambda_u}}{\delta w_u - \frac{t_u \lambda_u}{2}}\right)$, meaning that farmers keep entering the market until the market share of the latest entrant reaches a floor value.

	No externality	With externalities	
		space-invariant (homogeneous case)	spatially-varying (heterogeneous case)
	$e(t(x), q(x, \lambda_u)) = 1 \; \forall \; x$	$e(t(x), q(x, \lambda_u)) = \hat{e}(t, h(\lambda_u)) \; \forall \; x$	$e(t(x), q(x, \lambda_u))$
Urban net income (ζ_u^*)	$w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}$	$w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}$	$w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}(\frac{\bar{e}_u}{\bar{e}})^\eta$
Goods quality (θ^*)	$\frac{\frac{\bar{\theta} p_z(1+\sigma\beta)}{\sigma(1-\beta)-1}}{\bar{R}}$	$\frac{\frac{\bar{\theta} p_z(1+\sigma\beta)}{\sigma(1-\beta)-1}}{\bar{R}}$	$\frac{\frac{\bar{\theta} p_z(1+\sigma\beta)}{\sigma(1-\beta)-1}}{\bar{R}} \left[\frac{\bar{e}}{e(t(x),q(x,\lambda_u))}\right]^\eta$
Goods quantity (q^*)	$\frac{(\sigma(1-\beta)-1)\bar{R}}{p_z(1+\sigma\beta)}$	$\frac{(\sigma(1-\beta)-1)\bar{R}}{p_z(1+\sigma\beta)}\hat{e}(t, q(\lambda_u))$	$\frac{(\sigma(1-\beta)-1)\bar{R}}{p_z(1+\sigma\beta)} \left[\frac{e(t(x),q(x,\lambda_u))^{\eta+1}}{\bar{e}^\eta}\right]$
Environmental Impact (EI)	$\alpha\psi\lambda_u\zeta_u^* \frac{(\sigma(1-\beta)-1)}{p_z(1+\sigma\beta)}$	$\alpha\psi\lambda_u\zeta_u^* \frac{(\sigma(1-\beta)-1)}{p_z(1+\sigma\beta)}$	$\frac{(\sigma(1-\beta)-1)}{p_z(1+\sigma\beta)} \frac{\bar{R}}{\bar{s}}$

Table 2: *Urban net income, quality, quantity and 'greenness' at the long-run equilibrium.*

the impact of externalities on the degree of competition to acquire land. In the following, we propose to analytically study this relationship. For the sake of clarity, we proceed in two steps.

City size and local farming with space-invariant externalities $\hat{e}(t, q(\lambda_u))$. Consider first that externalities do not vary in space. In this case, the relationship between the range of varieties at the free-entry equilibrium and the size of the urban population is given by the Cartesian equation $\alpha\psi\lambda_u - \frac{\bar{R}\hat{\lambda}_a^*}{w_u - \frac{t_u}{2\delta}\lambda_u - \frac{\bar{R}}{\delta}} = 0$ leading to:

$$\hat{\lambda}_a^*(\lambda_u) = \frac{\alpha\psi\lambda_u}{\bar{R}} \left(w_u - \frac{t_u}{2\delta}\lambda_u - \frac{\bar{R}}{\delta} \right) \tag{24}$$

Eq.(24) describes a concave curve, coming from the interplay of two standard competing effects in urban economics: (i) a market size effect that plays positively and linearly, leading farmers to enter the local market so as to benefit from the additional consumers, and (ii) a (negative) net income effect –*through a fiercer competition between urban households on the land market and thereby, an increase in housing cost*– which restricts the expenditures in local food at an increasing rate. The range of food varieties rises as long as the market size effect outweighs the net income effect. Then, it reaches a threshold value beyond which, any further urban population growth would lead to a decline in variety.

Proposition 4.1 *In presence of space-invariant externalities, local farming is more likely to provide a wider range of varieties in regions hosting an intermediate-size city.*

City size and local farming with spatially-varying externalities. Since the function $e(t(x), q(x, \lambda_u))$ is not explicitly specified, solving the implicit Cartesian equation when externalities vary over space becomes much more complicated. However, recalling that $\pi(\lambda_u, \lambda_a^*)$ does not vary at the free-entry equilibrium ($\pi(\lambda_u, \lambda_a^*) = 0$) and using the total differential, we can draw the relationship between the urban population size and the number of varieties, given by $\frac{\partial \lambda_a^*}{\partial \lambda_u} = \frac{\partial \pi}{\partial \lambda_u} \times \left| \frac{\partial \pi}{\partial \lambda_s} \right|^{-1}$:

$$\frac{\partial \lambda_a^*}{\partial \lambda_u} = \frac{\phi \bar{s} - \bar{s}_u}{\phi \left(\bar{s} + \frac{\eta |e_x(\bar{x})|}{2\bar{e}} \right) - \bar{s}_u} \left[\frac{\partial \hat{\lambda}_a^*}{\partial \lambda_u} + \frac{\phi s_{\lambda_u}(\bar{x}) - s_{\lambda_u}(\bar{x}_u)}{(\phi \bar{s} - \bar{s}_u)\bar{s}} \right] \tag{25}$$

with the simplifying notations $s_{\lambda_u}(\bar{x}_u) \equiv \frac{\partial s}{\partial \lambda_u}(\bar{x}_u, \lambda_u, \lambda_a^*)$, $s_{\lambda_u}(\bar{x}) \equiv \frac{\partial s}{\partial \lambda_u}(\bar{x}, \lambda_u, \lambda_a^*)$, and $\phi \equiv \frac{\delta w_u - \frac{t_u \lambda_u}{2}}{\bar{R}}$.[10] Note that to make the comparison with the space-invariant case easier, Eq.(25) has been rearranged so as to let the expression $\frac{\partial \hat{\lambda}_a^*}{\partial \lambda_u}$ apparent. Doing so, it is readily verified that introducing spatial heterogeneity in productivity induces two major changes.

Regarding the land market first, the bid rent now differs from a farmer to the other, reaching higher prices than the opportunity cost of land $\bar{R}$ for all the locations benefiting from a better productivity coefficient than the border $\bar{x}$. To convince ourselves, we can calculate the free-entry equilibrium land rent by using (18) and (23):

$$R^*(x) = \begin{cases} \delta t_u(\bar{x}_u - x) + \bar{R} \left(\frac{\bar{e}_u}{\bar{e}} \right)^\eta & \text{if } 0 < x \leq \bar{x}_u \quad \textit{(urban area)} \\ \bar{R} \left(\frac{e(t(x), q(x, \lambda_u))}{\bar{e}} \right)^\eta & \text{if } \bar{x}_u < x \leq \bar{x}^* \quad \textit{(periurban farming area)} \\ \bar{R} & \text{if } x > \bar{x}^* \quad \textit{(conventional farming area)} \end{cases} \tag{26}$$

Farmers settled in high-productivity locations generate a larger operating profit and can outbid, which strengthens the competition on the land market and leads to a land cost increase. As a result, urban households have a lower net income to purchase food, entailing a weaker demand-side market potential, less incentive to enter the local market and, in turn, a smaller range of varieties. This spillover effect is captured by $\frac{\phi \bar{s} - \bar{s}_u}{\phi \left(\bar{s} + \frac{\eta |e_x(\bar{x})|}{2\bar{e}} \right) - \bar{s}_u} < 1$ and implies that, for the same city size, local farming would always provide a smaller set of varieties in a region displaying spatial heterogeneity.[11]

Second, spatial heterogeneity introduces distortions in competition between the producers engaged in the local market $\left(\frac{\phi s_{\lambda_u}(\bar{x}) - s_{\lambda_u}(\bar{x}_u)}{(\phi \bar{s} - \bar{s}_u)\bar{s}}\right)$. Because of the spatial variations in productivity, the market is not equally distributed among the farmers. Therefore, as previously mentioned, the increase in the size of the city affects the farmers differently according to their market share ($s_{\lambda_u}(x_a) \neq s_{\lambda_u}(x_b)$ if

[10] The details for the calculations are provided in Appendix C.

[11] Observe in this respect that, in the very specific case where externalities would be such that $\bar{e}_u = \bar{e}$ and $e(t(x), q(x, \lambda_u)) \geq \bar{e}\ \forall x \in]\bar{x}_u, \bar{x}[$, the land rent would describe a concave parabola that verifies $\varphi^*(\bar{x}_u) = \varphi^*(\bar{x})$ and this effect does not play.

$s(x_a) \neq s(x_b)$). Using the expressions of $s_{\lambda_u}(\bar{x})$ and $s_{\lambda_u}(\bar{x}_u)$ reported in Appendix D and rearranging, we show that:

$$\frac{\phi s_{\lambda_u}(\bar{x}) - s_{\lambda_u}(\bar{x}_u)}{(\phi\bar{s} - \bar{s}_u)\bar{s}} = \frac{\eta}{2\delta}\frac{\phi\bar{e}^{\eta-1}e_x(\bar{x}) - \bar{e}_u^{\eta-1}e_x(\bar{x}_u)}{(\phi\bar{e}^{\eta} - \bar{e}_u^{\eta})\bar{s}} + \frac{(\frac{\bar{e}_u}{\bar{e}})^{\eta} - 1}{\delta} + \frac{\eta|e_h h_{\lambda_u}|}{\bar{s}}\left(\xi - \frac{\phi\bar{e}^{\eta-1} - \bar{e}_u^{\eta-1}}{\phi\bar{e}^{\eta} - \bar{e}_u^{\eta}}\right) \quad (27)$$

where $\xi \equiv \frac{\int_{\bar{x}_u}^{\bar{x}} e(t(x),q(x,\lambda_u))^{\eta-1}dx}{\int_{\bar{x}_u}^{\bar{x}} e(t(x),q(x,\lambda_u))^{\eta}dx} > 1$ is the *sectoral shortfall rate* due to the externalities.[12]

The first term of (27) embeds the comparative effect of a change in productivity due to the marginal extra distance from the city center, which itself depends on the (negative) impact of the market access cost relative to the (positive) impact of moving away from the pollution source. The second term represents the marginal displacement of the periurban farming area within the regional space. The third and last part of (27) encapsulates the overall pollution intensity effect. It compares the sectoral shortfall rate ξ to the differential yield-losses at the boundaries $(\frac{\phi\bar{e}^{\eta-1} - \bar{e}_u^{\eta-1}}{\phi\bar{e}^{\eta} - \bar{e}_u^{\eta}}) > 1$ and can be either positive or negative.

In the end, it seems that, depending on the relative weight of each effect, the range of varieties can alternatively decrease or increase. It is worth noting that to get further insights would require additional assumptions on the shape and the variations of the productivity coefficient over space. Observe however that simple preliminary calculations reveal that the case where heterogeneity would favor the development in local farming occurs under very specific and restrictive conditions only. These include a wealthy urban population (ϕ high) and a nearly smooth spatial variation in externalities at $\bar{x}$ but sharp at $\bar{x}_u$ ($e_x(\bar{x}) \to 0$ and $e_x(\bar{x}_u) \ll 0$) *–so that* $\frac{\phi\bar{s} - \bar{s}_u}{\phi\left(\bar{s} + \frac{\eta|e_x(\bar{x})|}{2\bar{e}}\right) - \bar{s}_u} \to 1$ *and* $\frac{\phi s_{\lambda_u}(\bar{x}) - s_{\lambda_u}(\bar{x}_u)}{(\phi\bar{s} - \bar{s}_u)\bar{s}} > 0$. Finally, we derive the following proposition:

Proposition 4.2 *For the same city size, the local farming is more likely to provide a smaller range of varieties in a region displaying spatial heterogeneity in productivity, all things being equal.*

[12] See Appendix E for additional explanations on expected profit-loss rate, effective profit-loss rate and sectoral shortfall rate.

5 An illustrative application of the model

We finally offer an illustrative example. Let assume that the agricultural productivity coefficient follows :

$$e(t(x), q(x, \lambda_u)) = \left(\frac{1}{2} + \frac{\sin\left(\frac{\pi t}{a} x + \frac{\pi}{2}\right)}{2(1-b)\lambda_u^b} \right)^{\frac{1}{\eta}} \tag{28}$$

where t represents the market access cost, and a and b are two variability coefficients associated with (i) the impact of the distance from the city and (ii) the level of urban pollution on the land quality.

Figure (3) gives an illustration of the spatial variations in agricultural productivity, market shares (s) and the land allocation resulting from the land market equilibrium. As previously mentioned, the spatial distribution of the market shares follows the spatial variations of $e(t(x), q(x, \lambda_u))$. Observe besides that, in this case, exogenous parameters are such that, at the land market equilibrium, the space dedicated to agricultural production is enclosed in the natural area; because of the low levels in land quality at the urban fringe, the agricultural activity would not be sufficiently competitive to take place on these plots of land. Hence, the land allocation includes a greenbelt on the city boundary (see the brown square on the graph).

Using Eqs (4) and (21), we can calculate the environmental impact of local farming $EI(\lambda_u, \lambda_a)$ so as the quality and the quantity of agricultural varieties (See Figure (4)). Interestingly, the relationship between the environmental impact of local farming and the city size is not monotonic. Figure (5) even reveals that, if the spatial variability of externalities–*and therefore, land quality*– is strong, local farming can be 'greener' in intermediated-size cities than in small ones.

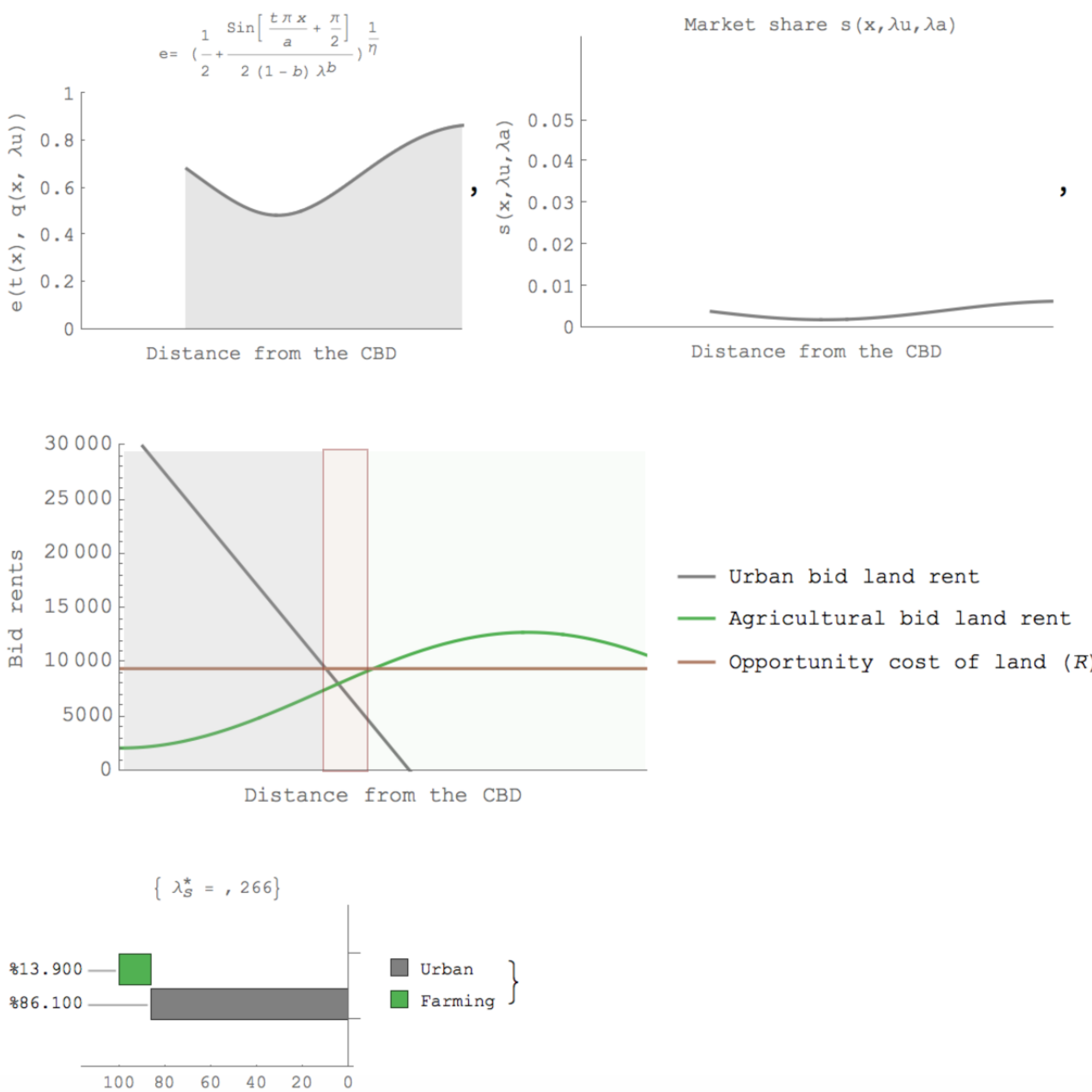

Figure 3: *Spatial variations in agricultural productivity (e), market shares (s) and land allocation.*

We finally determine the long-run equilibrium number of agricultural varieties (λ_a^*). Figure 6 has been realized for two city sizes and displays the cases of (i) space-invariant externalities (left) and (ii) spatially-varying externalities (right). The intersection between the demand-side market effect and the supply-side competition effect marks the equilibrium (red circles on the graph). The corresponding number of agricultural varieties is given by the value on the x-axis. This illustrative application allows to emphasize how the spatial heterogeneity in externalities modifies our benchmark results without externalities. Furthermore, it highlights that, given the set of parameters, there can be multiple equilibria (red line on the graph).

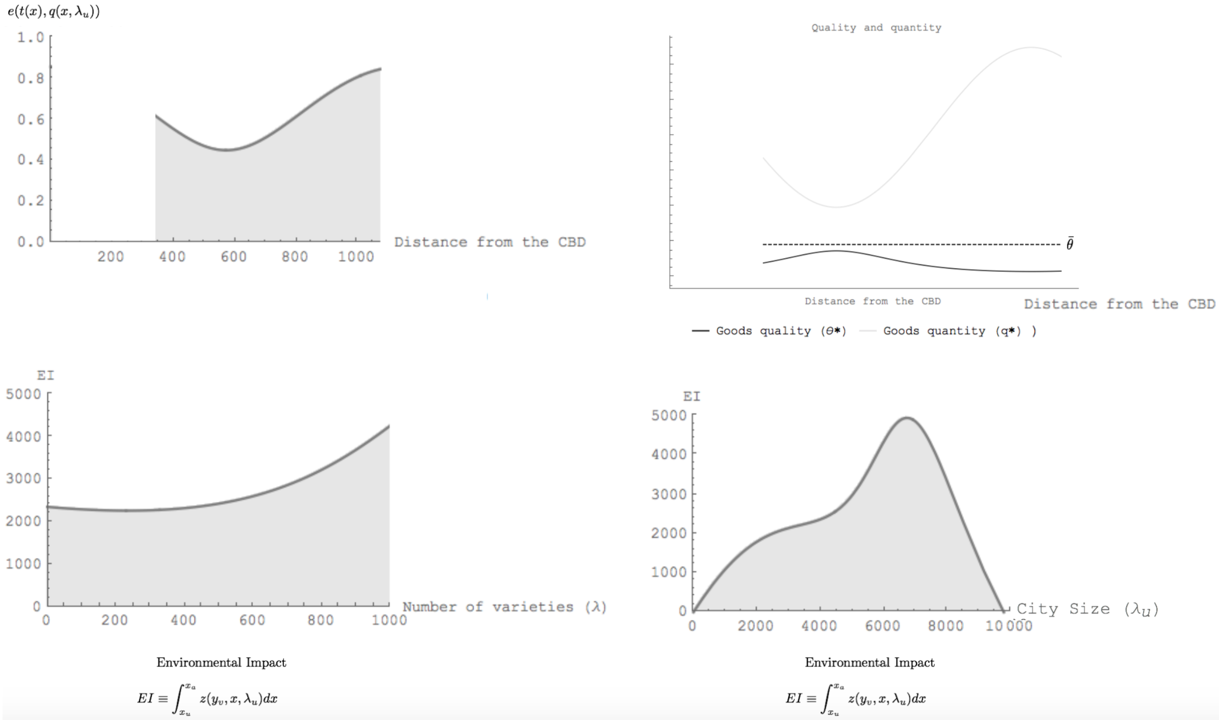

Figure 4: *Quality, quantity and environmental impact of agricultural varieties.*

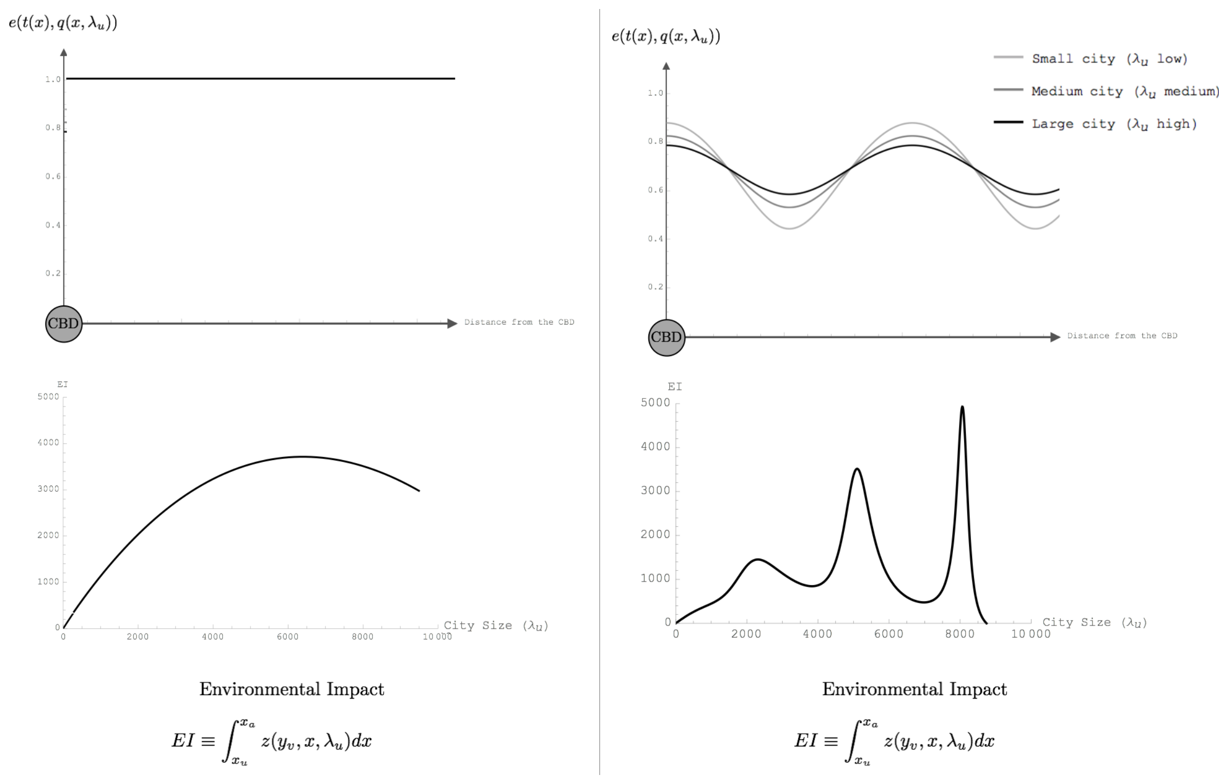

Figure 5: *The environmental impact of local agriculture with space-invariant externalities (left) and with spatially-varying externalities (right)*

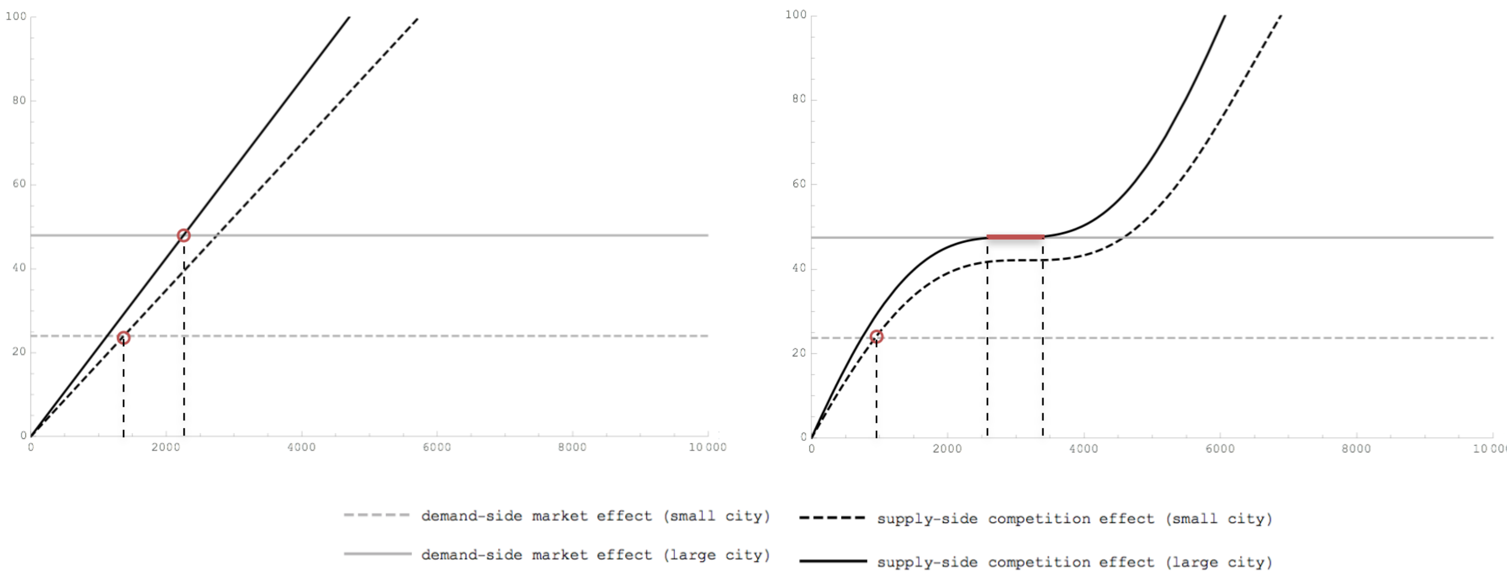

Figure 6: *Equilibrium number of agricultural varieties (λ_a^*) for two city sizes (λ_u low and high).*

6 Concluding remarks

The purpose of this paper was to develop a theoretical framework, with a high level of generalization but still analytically tractable, allowing to investigate whether feeding cities with locally grown products necessarily relies on a tradeoff between quality, affordability and sustainability. Regarding the relationship between the size of the urban population and local farming, we have shown that proximity to large cities may foster agricultural development provided that the market size effect dominates the net income effect. A corollary of this result is that regions hosting an intermediate-size city are likely to supply more varieties.

Additionally, we have studied how heterogeneity in productivity levels affects our benchmark results. We have highlighted that spatial heterogeneity in productivity creates distortions in competition between farmers; whilst the market is equally split between farmers in the homogeneous case, the spatial variations in productivity allow farmers that are located on the most productive plots of land to enjoy from an external rent, valued through a higher market share. By modifying the conditions to enter the market and thrive, spatial heterogeneity has concomitant undesired effects on both the quality, the price, the 'greenness' and the range of varieties, and may even lead to a situation where only few producers share the market, supplying low-quality goods. This finally stresses that accounting for heterogeneity is necessary to properly capture the implications of urban proximity on peri-urban development.

Admittedly, this paper only provides a partial view of the issue of agriculture viability in an increasingly urbanized space, but could be extended in several ways. Depending on the key motivation, some aspects such as the quality perception (impact of urban pollution on goods quality, soils contamination...), the features of the pollution, or the production technology (labor employment, farms size, mixed cropping) can be improved. The analysis can also be extended by enlarging the scope to cover other environmental and welfare issues related to urban-rural linkages. Regarding the public policy aspects for instance, a brief overview of our findings seems already to suggest that, as a rule, policies are required (i) to allow peri-urban farming to develop and thrive near highly-crowded cities –*provided that the market outcome is proven to be sub-optimal from a welfare standpoint*–, and (ii) to control for the potential distortions in competition in order to both enhance the quality and diminish the price of the available range of varieties.[13] Moreover, one must keep in mind that, although our focus was exclusively on the impact of cities on agriculture, the pollution issue is actually a two-way relationship. Thus, handling the welfare aspects would undeniably require to account for this feature.

[13]Note in this respect that, in 'Future of the CAP after 2013', the European Parliament [2010] makes clear that improving competitiveness at different levels, including local markets, should be a fundamental objective of the CAP post-2013.

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Appendix A: The land market equilibrium and land use

The equilibrium land rent is given by the upper envelop of bid rents, that is:

$$R(x) = \max\{\varphi_u(x), \varphi_a(x), \varphi_c(x)\} \tag{29}$$

$\varphi_u(x)$, $\varphi_a(x)$, and $\varphi_c(x)$ being the bid land rent of urban households, peri-urban farmers, and conventional farmers, respectively. For simplicity, we further assume that the conventional bid land rent equals to the opportunity cost of land $\bar{R}$.

The urban bid rent Plugging (9) into (6) and rearranging gives the indirect utility of urban households:

$$V_u(x) = \left(\frac{\alpha}{P}\right)^{\alpha} (1-\alpha)^{1-\alpha} \left(w_u - t_u x - \frac{R(x)}{\delta}\right) \tag{30}$$

At the residential equilibrium, the urban bid rent $\varphi_u(x)$ must solve $V_u'(x) = 0$ or equivalently, $\varphi_u^{'}(x) = -\delta t_u$, which solution is given by $\varphi_u(x) = \bar{R}_u - \delta t_u x$, $\bar{R}_u$ being a constant. Replacing $R(x)$ by the value of $\varphi_u(x)$ in Eq.(8), the urban net income becomes:

$$\zeta_u(x) \equiv w_u - \frac{\bar{R}_u}{\delta} = \zeta_u \tag{31}$$

which is the same across urban households, whatever their location.

The peri-urban bid rent Plugging the price index (11) into (13) and substituting $q(x, \lambda_u, \lambda_a)$ by the resulting expression in (5) gives the agricultural profit for a farmer located at x:

$$\pi(x, \lambda_u, \lambda_a) = [\alpha\psi\lambda_u\zeta_u \times s(x, \lambda_u, \lambda_a)] - R(x) \tag{32}$$

where $\psi \equiv \frac{1+\sigma\beta}{\sigma}$ is the *Lerner index* $(0 < \psi < 1)$.

The location choice for farmers is driven by two considerations. On the one hand, producing goods near the urban boundary allows reducing the market access cost. On the other hand, locating away from the city center allows farmers to be less affected by the urban pollution and, therefore, to reduce the yield losses. At the land market equilibrium, the peri-urban bid rent $\varphi_s(x)$ must solve $\partial\pi(x, \lambda_u, \lambda_a)/\partial x = 0$ or equivalently, ${\varphi_a}'(x) = \alpha\psi\lambda_u\zeta_u \times s_x$, which solution is given by:

$$\varphi_a(x, \lambda_u, \lambda_a) = \bar{R}_s + \alpha\psi\lambda_u\zeta_u \; s(x, \lambda_u, \lambda_a) \tag{33}$$

$\bar{R}_s$ being a constant. Note from (33) that, because of the negative relationship between the market shares and the number of competitors, the bids from peri-urban farmers are also decreasing with λ_s.

Land use equilibrium Depending on the ranking of bid rent curves, several land use configurations can occur. For our study, we concentrate on the case where the zone dedicated to farming is located at the periphery of the city and right-bordered by the natural area. Mathematically, the agricultural bid land rent must verify $\varphi_a(x) > \bar{R}\ \forall x \in [\bar{x}_u; \bar{x}[$ and $\varphi_a(x) < \bar{R}\ \forall x > \bar{x}$ which notably implies that:

1. $\varphi_a(x)$ is decreasing at $\bar{x}$.
2. The agricultural bid land rent at the urban fringe must be at least equal to the opportunity cost of land ($\varphi_a(\bar{x}_u) \geq \bar{R}$), entailing in turn $e(t(\bar{x}_u), q(\bar{x}_u, \lambda_u)) \geq e(t(\bar{x}), q(\bar{x}, \lambda_u))$. This condition ensures that configurations where the peri-urban area is enclosed in the natural area can not occur.

In the following, these two conditions are supposed to be verified. Then, knowing that the agricultural bid rent must equalize the opportunity cost of land at $\bar{x}$, we find $\bar{R}_a = \bar{R} - \alpha\psi\lambda_u\zeta_u s(\bar{x}, \lambda_u, \lambda_a)$, so that we now have:

$$\varphi_a(x) = \bar{R} + \alpha\psi\lambda_u\zeta_u[s(x, \lambda_u, \lambda_a) - s(\bar{x}, \lambda_u, \lambda_a)] \tag{34}$$

Analogously, we know that urban bid rent and agricultural bid rent must equalize at the urban fringe $\bar{x}_u$. Hence, replacing ζ_u by its value in (34) and equating $\varphi_u(\bar{x}_u)$ to $\varphi_a(\bar{x}_u)$ yields:

$$\bar{R}_u = \frac{\bar{R} + t_u\frac{\lambda_u}{2} + \alpha\psi\lambda_u\frac{\bar{e}_u^\eta - \bar{e}^\eta}{S}w_u}{\frac{\alpha\psi\lambda_u}{\delta}\frac{\bar{e}_u^\eta - \bar{e}^\eta}{S} + 1} \quad \text{and} \quad \bar{R}_a = \bar{R} - \frac{(\delta w_u - t_u\frac{\lambda_u}{2} - \bar{R})\bar{e}^\eta}{\frac{\delta S}{\alpha\psi\lambda_u} + \bar{e}_u^\eta - \bar{e}^\eta} \tag{35}$$

Then, plugging $\bar{R}_u$ into the urban and the agricultural bid land rents leads to:

$$\varphi_u(x) = \delta\left(w_u - \zeta_u^m(\lambda_u, \lambda_a) - t_u x\right) \quad \text{and} \quad \varphi_a(x) = \alpha\psi\lambda_u\zeta_u^m(\lambda_u, \lambda_a)\frac{e(t(x), q(x, \lambda_u))^\eta - \bar{e}^\eta}{S(\lambda_u, \lambda_a)} + \bar{R} \tag{36}$$

where $\zeta_u^m(\lambda_u, \lambda_a)$ is the urban net income at the land market equilibrium:

$$\zeta_u^m(\lambda_u, \lambda_a) \equiv \frac{w_u - t_u\frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}}{\frac{\alpha\psi\lambda_u}{\delta}\frac{\bar{e}_u^\eta - \bar{e}^\eta}{S(\lambda_u, \lambda_a)} + 1} \tag{37}$$

The agricultural bid rent follows the spatial variations of $e(t(x), q(x, \lambda_u))$; it is thus decreasing with the distance from the CBD if the effect of the market access cost dominates that of the land quality, and increasing otherwise. Combining (29) and (36), the equilibrium land rent is finally given by:

$$R^m(x, \lambda_u, \lambda_a) = \begin{cases} \delta\left(w_u - \zeta_u^m(\lambda_u, \lambda_a) - t_u x\right) & \text{if } 0 < x \leq \bar{x}_u \ \textit{(urban area)} \\ \alpha\psi\lambda_u\zeta_u^m(\lambda_u, \lambda_a)\dfrac{e(t(x), q(x, \lambda_u))^\eta - \bar{e}^\eta}{S(\lambda_u, \lambda_a)} + \bar{R} & \text{if } \bar{x}_u < x \leq \bar{x} \ \textit{(agricultural area)} \\ \bar{R} & \text{if } x > \bar{x} \ \textit{(natural area)} \end{cases} \tag{38}$$

Appendix B: Market share

The market share of the farmer located at x is given by:

$$s(x, \lambda_u, \lambda_a) = \frac{e(t(x), q(x, \lambda_u))^\eta}{S(\lambda_u, \lambda_a)} \qquad (0 \leq s(x, \lambda_u, \lambda_a) \leq 1) \tag{39}$$

where $S(\lambda_u, \lambda_a) \equiv 2\int_{X_s} e(t(x), q(x, \lambda_u))^\eta dx$ captures the *supply-side market potential* of local food production. Differentiating $S(\lambda_u, \lambda_a)$ with respect to λ_u yields:

$$S_{\lambda_u}(\lambda_u, \lambda_a) = -2 \times \left[\eta |e_q q_{\lambda_u}| \int_{\bar{x}_u}^{\bar{x}} e(t(x), q(x, \lambda_u))^{\eta-1} dx + \frac{\bar{e}_u^\eta - \bar{e}^\eta}{2\delta}\right] < 0 \tag{40}$$

Market share and supply-side competition. The variation of the market shares in each location with respect to the number of farmers λ_s is given by:

$$s_{\lambda_a}(x, \lambda_u, \lambda_a) = -\frac{e(t(x), q(x, \lambda_u))^\eta \times e(t(\bar{x}), h(\bar{x}, \lambda_u))^\eta}{S(\lambda_u, \lambda_a)^2} = -s(x, \lambda_u, \lambda_a)\bar{s} < 0 \tag{41}$$

highlighting that the market share is always decreasing with the number of competitors.

Appendix C: Agricultural profit and competition.

Using the expression of the market share s, the equilibrium profit can be rewritten as:

$$\pi^m(\lambda_u, \lambda_a) = \frac{\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R}}{\bar{s}_u - \bar{s} + \frac{\delta}{\alpha \psi \lambda_u}} \times \bar{s} - \bar{R} \tag{42}$$

Calculating the derivative of (42) with respect to λ_a gives:

$$\begin{aligned} \frac{\partial \pi^m}{\partial \lambda_a} &= \frac{-[\bar{s}^2(\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R})(\bar{s}_u - \bar{s} + \frac{\delta}{\alpha \psi \lambda_u})] - [\bar{s}(\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R})(\bar{s}^2 - \bar{s}_u \bar{s})]}{(\bar{s}_u - \bar{s} + \frac{\delta}{\alpha \psi \lambda_u})^2} \\ &= -\frac{\frac{\delta}{\alpha \psi \lambda_u}}{(\bar{s}_u - \bar{s} + \frac{\delta}{\alpha \psi \lambda_u})^2} < 0 \end{aligned} \tag{43}$$

Appendix D: Free-entry equilibrium and the size of the urban population.

City size and local farming with space-invariant externalities $\hat{e}(t, q(\lambda_u))$. When externalities do not vary in space, the number of agricultural varieties at the long-run equilibrium is given by:

$$\hat{\lambda}_a^*(\lambda_u) = \frac{\alpha \psi \lambda_u}{\delta \bar{R}} \left(\delta w_u - \frac{t_u}{2} \lambda_u - \bar{R}\right) \tag{44}$$

and its derivative with respect to λ_u is:

$$\frac{\partial \hat{\lambda}_a^*}{\partial \lambda_u} = \frac{\alpha \psi}{\delta \bar{R}} \left(\delta w_u - t_u \lambda_u - \bar{R}\right) \tag{45}$$

City size and local farming with spatially-varying externalities. Recalling that $\pi(\lambda_u, \lambda_a^*)$ does not vary at the free-entry equilibrium ($\pi(\lambda_u, \lambda_a^*) = 0$) and using the total differential, we can draw the relationship between the urban population size and the number of varieties, given by $\frac{\partial \lambda_a^*}{\partial \lambda_u} = \frac{\partial \pi}{\partial \lambda_u} \times \left| \frac{\partial \pi}{\partial \lambda_a} \right|^{-1}$. Differentiating (20) with respect to λ_a and λ_u, and evaluating at the free-entry equilibrium yields:

$$\frac{\partial \pi}{\partial \lambda_a}(\lambda_u, \lambda_a^*) = -\frac{\bar{R}^2}{\delta \bar{w}_u} \left[\phi \left(\bar{s} + \frac{\eta |e_x(\bar{x})|}{2\bar{e}} \right) - \bar{s}_u \right] < 0 \quad \text{and} \tag{46}$$

$$\frac{\partial \pi}{\partial \lambda_u}(\lambda_u, \lambda_a^*) = \frac{\bar{R}^2}{\delta \bar{w}_u} \left(\frac{\phi \bar{s} - \bar{s}_u}{\lambda_u \bar{s}} - \frac{t_u}{2\bar{R}} + \frac{\phi s_{\lambda_u}(\bar{x}, \lambda_u, \lambda_a^*) - s_{\lambda_u}(\bar{x}_u, \lambda_u, \lambda_a^*)}{\bar{s}} \right) \tag{47}$$

where $e_x(\bar{x}) \equiv \frac{\partial e}{\partial t} t'(\bar{x}) + \frac{\partial e}{\partial q} \frac{\partial q}{\partial x}(\bar{x})$ is the spatial variation of the productivity coefficient at $\bar{x}$ and with the simplifying notations $\phi \equiv \frac{\delta w_u - \frac{t_u \lambda_u}{2}}{\bar{R}}$, $\bar{s}_u \equiv s(\bar{x}_u, \lambda_u, \lambda_a^*)$, and $\bar{s} \equiv s(\bar{x}, \lambda_u, \lambda_a^*)$. Then, using $\frac{\partial \lambda_a^*}{\partial \lambda_u} = \frac{\partial \pi}{\partial \lambda_u} \times \left| \frac{\partial \pi}{\partial \lambda_a} \right|^{-1}$, it is readily verified that the relationship between the urban population size and the number of agricultural varieties when externalities are varying over space is:

$$\frac{\partial \lambda_a^*}{\partial \lambda_u} = \frac{1}{\phi \left(\bar{s} + \frac{\eta |e_x(\bar{x})|}{2\bar{e}} \right) - \bar{s}_u} \left(\frac{\phi \bar{s} - \bar{s}_u}{\lambda_u \bar{s}} - \frac{t_u}{2\bar{R}} + \frac{\phi s_{\lambda_u}(\bar{x}, \lambda_u, \lambda_a^*) - s_{\lambda_u}(\bar{x}_u, \lambda_u, \lambda_a^*)}{\bar{s}} \right) \tag{48}$$

Eq. (48) can be rearranged so as to make $\frac{\partial \hat{\lambda}_a^*}{\partial \lambda_u}$ apparent:

$$\frac{\partial \lambda_a^*}{\partial \lambda_u} = \frac{\phi \bar{s} - \bar{s}_u}{\phi \left(\bar{s} + \frac{\eta |e_x(\bar{x})|}{2\bar{e}} \right) - \bar{s}_u} \left[\frac{\partial \hat{\lambda}_a^*}{\partial \lambda_u} + \frac{\phi s_{\lambda_u}(\bar{x}, \lambda_u, \lambda_a^*) - s_{\lambda_u}(\bar{x}_u, \lambda_u, \lambda_a^*)}{(\phi \bar{s} - \bar{s}_u)\bar{s}} \right] \tag{49}$$

Calculating the derivatives of the market share at the periurban boundaries $\bar{x}_u$ and $\bar{x}$ with respect to the city size gives:

$$\frac{\partial s}{\partial \lambda_u}(\bar{x}_u, \lambda_u, \lambda_a^*) \equiv s_{\lambda_u}(\bar{x}_u) = \bar{s}_u \left[\frac{\eta e_x(\bar{x}_u)}{2\delta \bar{e}_u} + \frac{\bar{s}_u - \bar{s}}{\delta} + \eta |e_q q_{\lambda_u}| \left(\xi - \frac{1}{\bar{e}_u} \right) \right] \tag{50}$$

and

$$\frac{\partial s}{\partial \lambda_u}(\bar{x}, \lambda_u, \lambda_a^*) \equiv s_{\lambda_u}(\bar{x}) = \bar{s} \left[\frac{\eta e_x(\bar{x})}{2\delta \bar{e}} + \frac{\bar{s}_u - \bar{s}}{\delta} + \eta |e_q q_{\lambda_u}| \left(\xi - \frac{1}{\bar{e}} \right) \right] \tag{51}$$

with the simplifying notation $\xi \equiv \frac{\int_{\bar{x}_u}^{\bar{x}} e(t(x), q(x, \lambda_u))^{\eta - 1} dx}{\int_{\bar{x}_u}^{\bar{x}} e(t(x), q(x, \lambda_u))^{\eta} dx}$. Then, using (50) and (51), we find:

$$\frac{\phi s_{\lambda_u}(\bar{x}) - s_{\lambda_u}(\bar{x}_u)}{(\phi \bar{s} - \bar{s}_u)\bar{s}} = \frac{\eta}{2\delta} \frac{\phi \bar{e}^{\eta-1} e_x(\bar{x}) - \bar{e}_u^{\eta-1} e_x(\bar{x}_u)}{(\phi \bar{e}^{\eta} - \bar{e}_u^{\eta})\bar{s}} + \frac{(\frac{\bar{e}_u}{\bar{e}})^{\eta} - 1}{\delta} + \frac{\eta |e_h h_{\lambda_u}|}{\bar{s}} \left(\xi - \frac{\phi \bar{e}^{\eta-1} - \bar{e}_u^{\eta-1}}{\phi \bar{e}^{\eta} - \bar{e}_u^{\eta}} \right) \tag{52}$$

Appendix E: The sectoral shortfall rate.

As previously mentioned, $e(t(x), q(x, \lambda_u))^{-1}$ represents the yield-loss factor–*that is the differential between the effective yields and the theoretical yields that would be obtained without externalities.* $e(t(x), q(x, \lambda_u))^{-1}$ can thus also be interpreted as the expected profit-loss factor, which differs from the effective profit-loss factor given by $e(t(x), q(x, \lambda_u))^{-\eta}$ (See Eq.15). The ratio of these two elements gives $e(t(x), q(x, \lambda_u))^{\eta-1}$, which can be interpreted as a shortfall factor due to the externalities, that is, the total deviation from the theoretical profit stemming from the fact that farmers take the effective yields into account when choosing the quantity of synthetic inputs and setting their price. Stated differently, $e(t(x), q(x, \lambda_u))^{\eta-1}$ can be seen as an adaptation (hidden) cost expressed as a ratio between the expected and the effective profit-loss. When it is summed over the whole market, we obtain the aggregate shortfall factor for the local farming sector $\int_{\bar{x}_u}^{\bar{x}} e(t(x), q(x, \lambda_u))^{\eta-1}dx$. Finally, reported on the aggregate profit-loss rate $\int_{\bar{x}_u}^{\bar{x}} e(t(x), q(x, \lambda_u))^{\eta}dx$, we get:

$$\frac{\int_{\bar{x}_u}^{\bar{x}} e(t(x), q(x, \lambda_u))^{\eta-1}dx}{\int_{\bar{x}_u}^{\bar{x}} e(t(x), q(x, \lambda_u))^{\eta}dx} > 1 \tag{53}$$

which captures the weight of the shortfall factors in the effective profit-loss factors at the sector level, referred to as the *sectoral shortfall rate.*