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Abstract

In this paper, we study how the proximity to cities affects the decision of farmers to enter the direct-selling market in presence of spatial heterogeneity in agricultural yields. We develop a theoretical model which takes into account the externality of urban pollution and market access costs on direct-selling profits. We find that regions hosting an intermediate-size city are more likely to supply a wider range of direct-selling varieties. Additionally, we highlight that spatial heterogeneity in productivity creates distortions in competition between farmers, and can have concomitant undesired effects on both the quality and the range of available varieties.

Keywords: direct-selling farming, spatial heterogeneity, urban pollution, city size

JEL Classification: D43; Q13; Q53; R32

Agriculture en vente directe et externalités urbaines : impacts sur la variété et la qualité des produits

Résumé

Cet article propose une réflexion sur les conditions d'existence et de pérennisation d'une filière agricole en vente directe aux abords des grandes villes, en tenant compte d'effets externes négatifs liés à l'activité urbaine. On considère dans ce modèle que la proximité à la ville génère des externalités de pollution pouvant nuire aux rendements agricoles. Le modèle d'économie spatiale développé pour cette étude suppose que les agriculteurs ont le choix entre deux modèles de production, l'un conventionnel les conduisant à produire un bien homogène, l'autre de type « vente directe » où les biens sont verticalement et horizontalement différenciés. La résolution analytique de l'équilibre de marché permet de mettre en évidence l'existence d'une tension entre quantité et qualité de chacun des biens agricoles issus de la vente directe. Nous démontrons par ailleurs qu'à l'équilibre de libre-entrée, les villes de taille intermédiaire sont les plus en capacité d'offrir une grande variété de biens. Enfin, nous mettons en évidence que la variation des externalités dans l'espace conduit à introduire de l'hétérogénéité entre les producteurs, se traduisant par des distorsions de concurrence sur le marché de la vente directe et une gamme de variétés plus faible à taille de ville de donnée.

Mots-clefs : vente directe, hétérogénéité spatiale, pollution urbaine

Classification JEL : D43; Q13; Q53; R32

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1 Introduction

In many developed countries, the last two decades have seen a revival of short food supply chains (SFSCs) and local food systems –*i.e., systems whereby production, processing, trade and consumption occur within a particular narrowly defined geographical area, and the number of intermediaries is minimized*. As pointed out by Martinez *et al.* (2010) for the US market, SFSCs account for a growing share of the total agricultural sales, a sign that distribution networks are progressively changing in order to better meet the needs of customers.

In some extent, the recent global trend in SFSCs can be explained by the will of consumers to re-establish a long lasting relationship based on trust with farmers. In affluent cities in particular, consumers have increasing expectations regarding the quality, the provenance and the safety of the food they purchase (Deutsch *et al.*, 2013). Food supply crises such as the mad cow disease or the Belgian dioxin scandal have caused widespread anxiety among citizens (Miles and Frewer, 2001). In combination with concerns about safer food, a growing environmental awareness has also led consumers to question the 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 the consumers, but also to the 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 the producers to obtain a fairer share of the final sale price through the elimination of the intermediaries on the selling side, but also provide opportunities to diversify (Duarte 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 direct-selling 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 direct-selling development to be facilitated 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

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

kind of demand. In this 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, the existing research pays relatively little attention to the potential disincentive factors associated with urban environment that can also counter-balance the attractiveness of peri-urban areas and act as a brake to direct-selling 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, the competition to use the 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, and more precisely, the detrimental effects of urban pollution on crops. As now acknowledged by extensive research, urban pollution adversely affects the 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 of global yields due to ozone exposition could reach 3.9 to 15% for wheat, and 8.5 to 14% for soybean.[2] Still focusing on urban pollution, Holland *et al.* (2006) show that the directly-induced economic consequences are far from being negligible, establishing the losses for Europe in 2000 to 6.7 billion euros. With these elements in mind, the benefits of urban proximity can be seriously questioned.

In the existing literature, issues related to peri-urban agriculture have been mainly analyzed from the amenities standpoint, most of the works focusing on the impacts of agriculture and farmland on cities, but rarely the reverse. In fact, there are to our knowledge, only few theoretical formalizations that address urban-rural linkages with the farming sector as the primary focus. Among these contributions, attention has to be drawn to Lopez *et al.* (1988) and Wu *et al.* (2011). The first have developed a framework to estimate the effects of sub-urbanization on agricultural production choices, prices, and profits, and have found that, although vegetable production may benefit from urbanization, other agricultural sub-sectors such as grain crops or livestock are adversely affected. Wu *et al.* (2011) as for them, offer one of the most complete work from a theoretical standpoint. Investigating the effects of urbanization on the viability of farm-supporting sectors, they have built a model where opportunities lie on the benefits offered from being part of a large farming community, and have emphasized that the effect of urbanization on the agricultural infrastructure, inputs costs, and profit can be either positive or negative.

The purpose of this paper is to develop a theoretical framework enabling to investigate whether

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

direct-selling farming can develop in the neighboring of highly-crowded cities when the negative effects (externalities) associated to urban proximity are taken into account. We explore this question by building a spatial economic model (i) where farmers can choose between producing homogeneous conventional goods or direct-selling goods, and (ii) in which urban externalities on agricultural yields (namely, urban pollution and market access costs) are introduced.

Our modeling borrows from both spatial economic and monopolistic competition theories. We consider the direct-selling farming as a sector supplying urban households locally with arrays of horizontally- and vertically-differentiated goods sold under a market structure of monopolistic competition. Within this framework, the number of farmers engaged in direct-selling (and, in turn, the set of varieties) can be endogenously determined as a function of the urban population size. Regarding the spatial aspects, it follows the pioneering contribution of Alonso (1964); the economy is modeled as a monocentric city in which market access and urban pollution act as distance-dependent externalities. These externalities, depending on the size of the city and on the spread of the pollution over space, induce spatially-varying levels of productivity within the region, and lead us to deal with heterogeneity between farmers.[3] Hence, although farmers are supposed 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. For simplicity, and as a means to examine the direct-selling market in depth, we adopt a partial equilibrium approach, in the sense that the conventional farming and the urban sectors are not explicitly described. It is however worth noting that the inclusion of a land market allows to keep important urban-rural linkages.

As in standard non-spatial model displaying monopolistic competition, we find that the profit of farmers involved in direct-selling rises as the size of the population increases. However, when accounting for the spatial externalities related to the city size, the relationship becomes much more complex. We notably show that, in highly urban-crowded regions, only the most productive farmers can stay on the market because of the ever more intense competition to acquire land. As a result, regions hosting an intermediate-size city are more likely to supply a wider range of varieties. Additionally, we stress how spatial heterogeneity in productivity levels affects our standard results. We highlight that, by creating distortions in competition between farmers, heterogeneity can have concomitant undesired effects on both the quality and the range of available varieties. We notably provide some preliminary findings showing that increasing the urban pollution can alternatively foster or hinder the production of a direct-selling farmer relative to his competitors, with joint consequences on the quality of the goods supplied. We thus emphasize a quality-quantity-variety trade-off that truly depends on the shape and the variation of the productivity over space. This reinforces our previous statement that, when introducing the impact of externalities on a surrounding space, accounting for the potential

[3] In this respect, 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)].

heterogeneity is necessary to properly capture the implications of urban proximity on direct-selling development.

The paper proceeds as follows. Section 2 presents the model. In Section 3, we determine the market equilibrium, keeping the range of direct-selling varieties fixed, and we study how the relationship between quantity, 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 free-entry equilibrium and provides some insights on the relationship between market entry and the city size. Section 5 finally summarizes our conclusions and points out some possible extensions.

2 The framework

Consider an economy formed by a total population exogenously split into urban and rural households, and two sectors: a perfectly competitive sector, providing a homogeneous aggregate good, and an agricultural sector where farmers can choose between direct-selling or conventional marketing. Conventional farmers produce a homogeneous good under perfect competition, while farmers engaged in direct-selling operate under monopolistic competition and provide a quality-differentiated good through a short-supply chain.

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 inhabitants are supposed to be uniformly distributed across the city and consume a plot of fixed size $\frac{1}{\delta} - \delta$ *capturing thus the urban density, with* $\delta > 1$. 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 rural areas, located at the periphery of the city. Assuming that each farmer uses one unit of land to produce, the right endpoint of the region is given by:

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

where λ_s and λ_c stand respectively for the number of direct-selling farmers and conventional farmers.

We finally denote by $\bar{x}_s$ the boundary between direct-selling and conventional farming, and X_s the range of locations hosting direct-selling production. It is worth noting that, depending on the regional land allocation, the direct-selling farming takes place on plots such that $x \in [\bar{x}_u; \bar{x}_s]$ (near-city farming) or $x \in [\bar{x}_s; \bar{x}]$ (rural farming).

Urban pollution Rural areas are exposed to urban pollution, causing yield losses that are proportional to the level of pollution encountered in each location. The source of this pollution is located in the CBD and its intensity $h(x, \lambda_u)$ is supposed to be increasing with the level of urban activities ($h_{\lambda_u} > 0$), but decreasing with respect to the distance from the city center ($h(0, \lambda_u) > 0$ and $h_x < 0$).

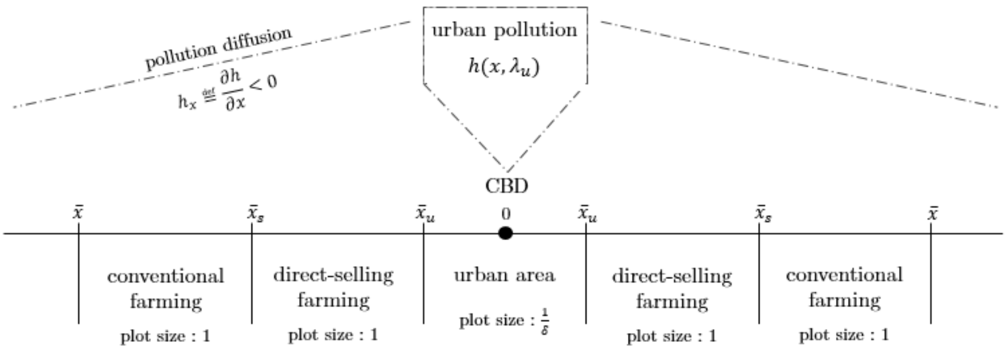


Figure 1: The spatial structure and urban pollution. In this example, the direct-selling farming locates at the urban fringe (near-city farming).

2.2 The direct-selling farming

Farmers engaged in direct-selling 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 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, direct-selling 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.

[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.

Production and externalities. The production function accounts for the effects of both market access costs and urban pollution on the total output. Denoting by $\bar{q}$ the natural ability of soils to grow crops in the region, we define the production for the variety v produced at x as:

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

where $0 < e(t(x), h(x, \lambda_u)) \leq 1$ stands for the agricultural productivity coefficient at x for a city size of λ_u – or similarly, $e(t(x), h(x, \lambda_u))^{-1} \geq 1$ corresponds to the *yield-loss rate*. The function e is decreasing with its two arguments $t(x)$ and $h(x, \lambda_u)$ and its value is influenced by the total space-related effect of location on the production level. Formally, it encompasses the impacts of pollution and market access costs, that operate in opposite directions as the distance from the CBD increases. It is readily verified that differentiating $e(t(x), h(x, \lambda_u))$ with respect to x yields $e_x \equiv \frac{\partial e}{\partial t}\frac{dt}{dx} + \frac{\partial e}{\partial h}\frac{\partial h}{\partial x} = -|e_t t'(x)| + |e_h h_x|$. Hence, from any location to the direct neighboring one further from the city center, the productivity is decreasing if the impact of market access costs ($|e_t t'(x)|$) outweighs the reduction in yield losses due to urban pollution ($|e_h h_x|$), and increasing otherwise.
In order to keep the discussion as broad as possible, we do not specify the shape of $e(t(x), h(x, \lambda_u))$. However, for the sake of tractability, we assume that the function is additively separable. This implies that there is no correlation between the yield losses due to the pollution and those due to the market access cost ($e_{t,h} = 0$). We also posit $e(0, 0) = 1$ meaning that, without spatial externalities, the agricultural production is given by the combination of soil quality and input use. Observe finally that when externalities are invariant in space (*i.e.* $e(t(x), h(x, \lambda_u)) = \hat{e}(t, h(\lambda_u))\ \forall x$), direct-selling farmers operate in a spatially-homogeneous competitive environment: they experience a same productivity level $\hat{e}(t, h(\lambda_u))$ and supply a same quantity $\hat{q}$ of a same quality $\hat{\theta}$.
Rewriting (3) so as to isolate z and setting $\bar{q} = 1$ for simplicity, yields the quantity of synthetic chemicals used by the farmer located at x:

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

We easily verify from (4) that supplying a large quantity of any variety always requires more inputs. Likewise, the use of synthetic chemicals is all the more intensive that the productivity coefficient at x is low.

The operating profit The profit of a direct-selling farmer 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 productivity-enhancing inputs, and $R(x)$ the unit rent of land at x, we have:

$$\pi_{s,v}(p_v, q_v, x, \lambda_u) = p_v \times q_v - [R(x) + p_z z(q_v, x, \lambda_u)] \tag{5}$$

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 direct-selling products.[5] In order to capture both the taste for variety and the consumers' relative valuation of goods' quality, we use the utility specification of Hallak (2006). Consumers share the same Cobb-Douglas preferences for two types of goods ; a homogeneous aggregate good M – *chosen as the numéraire and including the conventional agricultural good* – and direct-selling differentiated products:

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

with

$$Q = \left(\int_0^{\lambda_s} (\theta_v)^{\beta} (q_v)^{\frac{\sigma-1}{\sigma}} dv \right)^{\frac{\sigma}{\sigma-1}} \tag{7}$$

and where θ_v stands for the (perceived) quality of the variety v, $\sigma > 1$ is the elasticity of substitution between varieties, and β represents the intensity of preference for quality (with $0 < \beta < 1$). As desired, the utility is increasing with respect to the range of varieties λ_s and the quality.

Demand 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 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:

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

The demand for the composite good and the overall demand for direct-selling goods are derived from the maximization of the utility (6) subject to the (binding) budget constraint $PQ + M = \zeta_u(x)$:

$$M = (1 - \alpha)\zeta_u(x) \quad \text{and} \quad Q = \frac{\alpha \zeta_u(x)}{P} \tag{9}$$

where P is the price index for the range of direct-selling varieties supplied in the region.
We show in Appendix A that, at the residential equilibrium, the urban net income $\zeta_u(x)$ is invariant in space (see eq. (29)), implying that urban households have the same amount of direct-selling goods expenditures $\alpha\zeta_u$. Then, maximizing the sub-utility (7) subject to the constraint $\alpha\zeta_u = \int_0^{\lambda_s} p_v q_v dv$ leads to the following demand for the variety v:

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

[5] Interesting readers can refer to Abdel-Rahman (1988), Fujita (1988) or Ogawa (1998) for examples of models introducing Chamberlinian monopolistic competition and taste-for-variety à la Dixit and Stiglitz (1977) into an Alonso (1964) type model featuring a continuous location-space.

with

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

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

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

$\bar{\theta}$ being the maximum quality level. Observe that quality here rather refers to subjectively 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 q_v yields:

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

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

2.4 The market structure

Direct-selling 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 direct-selling farmer sets his price so as to maximize his profit and taking the price index P as a constant. Plugging (13) into (5) and equating the first derivative of $\pi_{s,v}(p_v, x, \lambda_u)$ with respect to p_v to zero yields the equilibrium price of the variety v produced at x:[7]

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

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 $x \in X_s$ 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

[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, $\pi_{s,v}(p_v, x, \lambda_u)$ is concave in p_v for $p < \frac{p_z}{e(t(x),h(x,\lambda_u))} \frac{\sigma+(1+\sigma\beta)}{\sigma-(1+\sigma\beta)}$, a condition verified at the equilibrium price.

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 urban pollution and market access costs to consumers.

Market share and competition Using equations (4) and (11)–(14) to calculate the price index P, re-injecting its value in (13), and multiplying the resulting expression of q by p^m, we obtain the receipts of the direct-selling farmer located at x:

$$r(x, \lambda_u, \lambda_s) = \frac{\alpha \zeta_u \lambda_u}{S(\lambda_u, \lambda_s)} e(t(x), h(x, \lambda_u))^\eta \tag{15}$$

where $S(\lambda_u, \lambda_s) \equiv 2\int_{X_s} e(t(x), h(x, \lambda_u))^\eta dx$ captures the *supply-side market potential* of direct-selling food production. The higher $S(\lambda_u, \lambda_s)$, the greater the possibility for direct-selling farming to produce large quantities of each variety (*intensive margin*) or, alternatively, a large range of varieties (*extensive margin*). Besides, we show in Appendix B that $S(\lambda_u, \lambda_s)$ 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 of the direct-selling farmer located at x:

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

As readily shown from (15), the numerator $e(t(x), h(x, \lambda_u))^\eta$ 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 $e(t(x), h(x, \lambda_u))$ and when productivity is homogeneous over space ($e(t(x), h(x, \lambda_u)) = \hat{e}(t, h(\lambda_u)) \; \forall \; x$), direct-selling farmers have a same market share given by $\hat{s} = \frac{1}{\lambda_s}$.

2. The market share is always decreasing with the number of competitors λ_s and the larger the weight of the farmer located at x, the greater his loss in market share.

3. The market share is increasing with the urban pollution $h(x, \lambda_u)$ 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 a 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 direct-selling market.*

3 Direct-selling 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 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:

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

$\varphi_u(x)$, $\varphi_s(x)$, and $\varphi_c(x)$ being the bid land rent of urban households, direct-selling farmers, and conventional farmers, respectively.

Depending on ranking of the bid rent curves, several land use configurations can occur. For our study, we concentrate on the case where the zone dedicated to direct-selling farming is located at the periphery of the city and right-bordered by the conventional farming area (*i.e.* $X_s = [\bar{x}_u; \bar{x}_s]$). Besides, we assume for simplicity that the conventional bid land rent equals the opportunity cost of land $\bar{R}$. For the ease of reading, the details of the resolution are reported in Appendix A. As showed therein, the equilibrium land rent is given by:

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

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

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

and $\bar{e}_u$ and $\bar{e}$ stand respectively for the productivity coefficient at each edge of the direct-selling area (*i.e.*, $e(t(\bar{x}_u), h(\bar{x}_u, \lambda_u)$ and $e(t(\bar{x}), h(\bar{x}, \lambda_u))$.[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 direct-selling farmers can outbid, the larger the denominator, and the smaller the net income. Interestingly, we can observe that when the

[8] In our model, ψ represents the bargaining power of direct-selling producers relative to the consumers.

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 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, location and goods quality

Using equations (15) and (18)–(19) in (5) and rearranging, yields the direct-selling market equilibrium profit:

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

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

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

The terms in square brackets embed all the effects stemming from the introduction of spatial externalities. $q^m(x, \lambda_u, \lambda_s)$ and $\theta^m(x, \lambda_u, \lambda_s)$ vary in opposite direction with respect to the productivity level $e(t(x), h(x, \lambda_u))$; letting x_a and x_b be two neighboring locations such that $\bar{x}_u < x_a < x_b < \bar{x}_s$, we can state that $q^m(x_a, \lambda_u, \lambda_s) > q^m(x_b, \lambda_u, \lambda_s)$ and $\theta^m(x_a, \lambda_u, \lambda_s) < \theta^m(x_b, \lambda_u, \lambda_s)$ provided that $e(t(x_a), h(x_a, \lambda_u)) > e(t(x_b), h(x_b, \lambda_u))$.

The implication in terms of goods quality may be counter-intuitive. Indeed, since the use of chemicals inputs z is decreasing with respect to $e(t(x), h(x, \lambda_u))$, 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 direct-selling market, we find that the quality of any variety is improving with the gap in productivity $(\bar{e}_u - \bar{e}_s)$. As showed by (19), an increase in $(\bar{e}_u - \bar{e}_s)$ induces a loss in urban net income, due to a fiercer competition on the land market. The demand for direct-selling 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 $S(\lambda_s, \lambda_u)$. This can either come from a larger number of direct-selling varieties λ_s, leading to a more competitive market and a fragmentation of the consumer demand, or from an enhancement in the productivity coefficient levels $e(t(x), h(x, \lambda_u)$, resulting in a decrease in synthetic inputs use.

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 and the quantity. 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.

Table 1: Urban net income, quality and quantity under no externality, space-invariant externalities, and spatially-varying externalities.

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

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 direct-selling 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 a same market share, implying that the bid land rent for direct-selling 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 the yield losses, 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 direct-selling farmers. Depending on their location, they are unevenly affected by the yield losses and do not provide a same quantity of goods. Hence, although the productivity coefficients decline for all the locations, restricting the technical possibility to grow crops, farmers enjoying better yields 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:

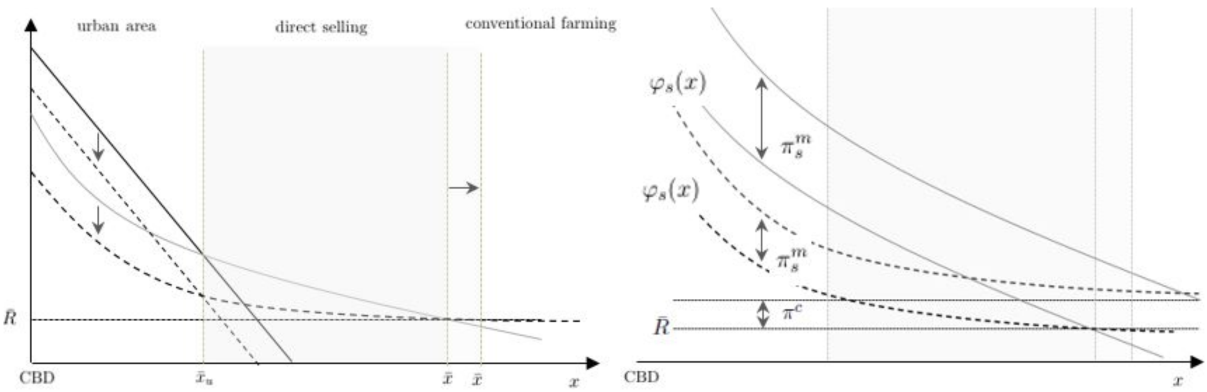
Proposition 3.1 *Increasing the level of urban pollution affects the quality and the quantity of direct-selling goods in different ways depending whether externalities are varying over space or not.*

This proposition raises an essential question regarding the adequate range of direct-selling varieties. So far, the number of farmers engaged in direct-selling 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 direct-selling market drives the profits down while entailing a decrease in the direct-selling bid rent, which tends to smooth over space (as illustrated by Figure (2)). Farmers keep entering the direct-selling market as long as the profit they can earn stays higher than the (exogenous) equilibrium profit prevailing in conventional farming π_c.

Figure 2: Direct-selling farmers entrance, land allocation and profits.



4.1 The equilibrium number of direct-selling varieties.

Since the agricultural profit is decreasing with the number of farmers involved in direct-selling, the free-entry equilibrium is ensured to be a unique stable interior solution. Let assume zero profit for conventional agriculture. Then, solving $\pi_s^m(\lambda_u, \lambda_s) = \pi_c = 0$, the number of direct-selling varieties at the free-entry equilibrium λ_s^* must verify[9]:

$$\frac{\alpha\psi\lambda_u}{\delta} = \frac{S(\lambda_u, \lambda_s)}{\left(\frac{\delta w_u - \frac{t_u\lambda_u}{2}}{\bar{R}}\right)\bar{e}_s^\eta - \bar{e}_u^\eta} \tag{22}$$

The left-hand side of (22) stands for the *demand-side market effect*. It is increasing with the urban population size and the Lerner index, and plays as a Home Market Effect (HME) ; as the size of the urban population rises, the incentive to enter the direct-selling market increases. The right-hand side captures the *supply-side competition effect* and is increasing with the number of direct-selling 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 direct-selling market. Observe finally that the existence of this equilibrium is ensured only provided that the difference in productivity between the farmers located at the direct-selling boundaries $\bar{x}_u$ and $\bar{x}_s$ is not too large, that is $1 > \frac{\bar{e}_s}{\bar{e}_u} > \left(\frac{\bar{R}}{\delta w_u - \frac{t_u\lambda_u}{2}}\right)^{\frac{1}{\eta}} > 0$.
Using the equilibrium condition (22), we can calculate the quantity and the quality of direct-selling goods at the free-entry equilibrium. These values are provided below.

Table 2: Urban net income, quality and quantity at the free-entry equilibrium.

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

Interestingly, Table 2 highlights that, compared to the homogeneous case, *the urban net income and the quality of direct-selling goods are always lower under heterogeneous productivity, while*

[9]Note that (22) can alternatively be written as $\bar{s}_s = \left(\bar{R} \times \frac{\bar{s}_u + \frac{\delta}{\alpha\psi\lambda_u}}{\delta w_u - \frac{t_u\lambda_u}{2}}\right)$, meaning that farmers keep entering the market until the market share of the latest entrant reaches a floor value.

the quantity of some varieties can be larger.

4.2 Direct-selling varieties and the city size.

The relationship between the urban population size and the range of direct-selling 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 direct-selling 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 productivity coefficient over space. Moreover, the inclusion of the land market brings additional spillover effects related to 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 direct-selling farming with space-invariant externalities $\hat{e}(t, h(\lambda_u))$. Consider first that externalities do not vary in space. In this case, the relationship between the range of direct-selling varieties at the free-entry equilibrium and the urban population size is given by the Cartesian equation $\alpha\psi\lambda_u - \frac{\bar{R}\hat{\lambda}_s^*}{w_u - \frac{t_u}{2\delta}\lambda_u - \frac{\bar{R}}{\delta}} = 0$ leading to:

$$\hat{\lambda}_s^*(\lambda_u) = \frac{\alpha\psi\lambda_u}{\bar{R}}\left(w_u - \frac{t_u}{2\delta}\lambda_u - \frac{\bar{R}}{\delta}\right) \tag{23}$$

Eq.(23) 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 direct-selling 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 direct-selling goods at an increasing rate. The range of direct-selling 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, direct-selling farming is more likely to provide a wider range of varieties in regions hosting an intermediate-size city.*

This proposition conveys an idea somewhat in line with Aguglia *et al.* (2008) ; testing whether direct-selling farming is more widely diffused in peri-urban areas, they have found both positive and negative coefficients, suggesting that the adoption of direct-selling is the result of trade-offs between advantages and drawbacks stemming from the proximity to urban centers.

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

$$\frac{\partial \lambda_s^*}{\partial \lambda_u} = \frac{\phi \bar{s}_s - \bar{s}_u}{\phi\left(\bar{s}_s + \frac{\eta |e_x(\bar{x}_s)|}{2\bar{e}_s}\right) - \bar{s}_u}\left[\frac{\partial \hat{\lambda}_s^*}{\partial \lambda_u} + \frac{\phi s_{\lambda_u}(\bar{x}_s) - s_{\lambda_u}(\bar{x}_u)}{(\phi \bar{s}_s - \bar{s}_u)\bar{s}_s}\right] \tag{24}$$

with the simplifying notations $\bar{s}_u \equiv s(\bar{x}_u, \lambda_u, \lambda_s^*)$, $\bar{s}_s \equiv s(\bar{x}_s, \lambda_u, \lambda_s^*)$, $s_{\lambda_u}(\bar{x}_u) \equiv \frac{\partial s}{\partial \lambda_u}(\bar{x}_u, \lambda_u, \lambda_s^*)$, $s_{\lambda_u}(\bar{x}_s) \equiv \frac{\partial s}{\partial \lambda_u}(\bar{x}_s, \lambda_u, \lambda_s^*)$, 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.(24) has been rearranged so as to let the expression $\frac{\partial \hat{\lambda}_s^*}{\partial \lambda_u}$ 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 direct-selling 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 $\bar{x}_s$. To convince ourselves, we can calculate the free-entry equilibrium land rent by using (18) and (22):

$$R^*(x) = \begin{cases} \delta t_u(\bar{x}_u - x) + \bar{R}\left(\frac{\bar{e}_u}{\bar{e}_s}\right)^\eta & \text{if } 0 < x \leq \bar{x}_u \text{ (urban area)} \\ \bar{R}\left(\frac{e(t(x), h(x, \lambda_u))}{\bar{e}_s}\right)^\eta & \text{if } \bar{x}_u < x \leq \bar{x}_s^* \text{ (direct-selling farming area)} \\ \bar{R} & \text{if } x > \bar{x}_s^* \text{ (conventional farming area)} \end{cases} \tag{25}$$

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 direct-selling market and, in turn, a smaller range of varieties. This spillover effect is captured by $\frac{\phi \bar{s}_s - \bar{s}_u}{\phi\left(\bar{s}_s + \frac{\eta |e_x(\bar{x}_s)|}{2\bar{e}_s}\right) - \bar{s}_u} < 1$ and implies that, for a same city size, direct-selling 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 direct-selling market ($\frac{\phi s_{\lambda_u}(\bar{x}_s) - s_{\lambda_u}(\bar{x}_u)}{(\phi \bar{s}_s - \bar{s}_u)\bar{s}_s}$). Because of the spatial variations in productivity, the market is not equally distributed among the farmers. Hence, as previously mentioned, increasing the urban population size applies with a different weight depending on the market share value. Using the expressions of $s_{\lambda_u}(\bar{x}_s)$ and $s_{\lambda_u}(\bar{x}_u)$ reported in Appendix C and rear-

[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 $\bar{e}_u = \bar{e}_s$ and $e(t(x), h(x, \lambda_u)) \geq \bar{e}_s \; \forall x \in]\bar{x}_u, \bar{x}_s[$, the land rent would describe a concave parabola that verifies $\varphi^*(\bar{x}_u) = \varphi^*(\bar{x})$ and this effect does not play.

ranging, we show that:

$$\frac{\phi s_{\lambda_u}(\bar{x}_s) - s_{\lambda_u}(\bar{x}_u)}{(\phi\bar{s}_s - \bar{s}_u)\bar{s}_s} = \frac{\eta}{2\delta}\frac{\phi\bar{e}_s^{\eta-1}e_x(\bar{x}_s) - \bar{e}_u^{\eta-1}e_x(\bar{x}_u)}{(\phi\bar{e}_s^{\eta} - \bar{e}_u^{\eta})\bar{s}_s} + \frac{(\frac{\bar{e}_u}{\bar{e}_s})^{\eta} - 1}{\delta} + \frac{\eta|e_h h_{\lambda_u}|}{\bar{s}_s}\left(\xi - \frac{\phi\bar{e}_s^{\eta-1} - \bar{e}_u^{\eta-1}}{\phi\bar{e}_s^{\eta} - \bar{e}_u^{\eta}}\right) \tag{26}$$

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

The first term of (26) 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 direct-selling farming area within the regional space. The third and last part of (26) 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 direct-selling 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 $\bar{x}_s$ but sharp at $\bar{x}_u$ ($e_x(\bar{x}_s) \to 0$ and $e_x(\bar{x}_u) \ll 0$) – *so that* $\frac{\phi\bar{s}_s - \bar{s}_u}{\phi\left(\bar{s}_s + \frac{\eta|e_x(\bar{x}_s)|}{2\bar{e}_s}\right) - \bar{s}_u} \to 1$ *and* $\frac{\phi s_{\lambda_u}(\bar{x}_s) - s_{\lambda_u}(\bar{x}_u)}{(\phi\bar{s}_s - \bar{s}_u)\bar{s}_s} > 0$. Finally, we derive the following proposition:

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

5 Concluding remarks

The purpose of this paper was to develop a theoretical framework, with a high level of generalization but still analytically tractable, enabling to investigate whether direct-selling farming can develop in the neighboring of highly-crowded cities when the negative effects (externalities) associated to urban proximity are taken into account. As regards to the relationship between the urban population size and direct-selling farming, we have shown that the proximity to large cities may foster direct-selling farming 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.

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

Additionally, we have studied how heterogeneity in productivity levels affects our standard 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 and the range of varieties, and may even lead to a situation where only few producers share the market, supplying large quantities of low-quality goods. This finally stresses that accounting for heterogeneity is necessary to properly capture the implications of urban proximity on direct-selling development.
Admittedly, this paper only provides a partial view of the issue of alternative farming 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 direct-selling 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 required 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:

$$R(x) = \max\{\varphi_u(x), \varphi_s(x), \varphi_c(x)\} \tag{27}$$

$\varphi_u(x)$, $\varphi_s(x)$, and $\varphi_c(x)$ being the bid land rent of urban households, direct-selling 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:

$$V_u(x) = \left(\frac{\alpha}{P}\right)^{\alpha} (1-\alpha)^{1-\alpha} \left(w_u - t_u x - \frac{R(x)}{\delta}\right) \tag{28}$$

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:

$$\zeta_u(x) \equiv w_u - \frac{\bar{R}_u}{\delta} = \zeta_u \tag{29}$$

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

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

$$\pi_s(x, \lambda_u, \lambda_s) = [\alpha\psi\lambda_u\zeta_u \times s(x, \lambda_u, \lambda_s)] - R(x) \tag{30}$$

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 direct-selling bid rent $\varphi_s(x)$ must solve $\partial\pi_s(x, \lambda_u, \lambda_s)/\partial x = 0$ or equivalently, ${\varphi_s}'(x) = \alpha\psi\lambda_u\zeta_u \times s_x$, which solution is given by:

$$\varphi_s(x, \lambda_u, \lambda_s) = \bar{R}_s + \alpha\psi\lambda_u\zeta_u \, s(x, \lambda_u, \lambda_s) \tag{31}$$

$\bar{R}_s$ being a constant. Note from (31) that, because of the negative relationship between the market shares and the number of competitors, the bids from direct-selling 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 direct-selling farming is located at the periphery of the city and right-bordered by the conventional farming area ($X_s = [\bar{x}_u; \bar{x}_s]$). Mathematically, the direct-selling bid land rent must verify $\varphi_s(x) > \bar{R}\ \forall x \in [\bar{x}_u; \bar{x}_s[$ and $\varphi_s(x) < \bar{R}\ \forall x > \bar{x}_s$ which notably implies that:

1. $\varphi_s(x)$ is decreasing at $\bar{x}_s$, meaning that, far from the city center, the market access cost always dominates the pollution cost (*i.e.* $|e_t \times t'(\bar{x}_s)| > |e_h \times h_x(\bar{x}_s)|$).

2. The direct-selling bid land rent at the urban fringe must be at least equal to the opportunity cost of land ($\varphi_s(\bar{x}_u) \geq \bar{R}$), entailing in turn $e(t(\bar{x}_u), h(\bar{x}_u, \lambda_u)) \geq e(t(\bar{x}), h(\bar{x}, \lambda_u))$. This condition ensures that configurations where the direct-selling area is enclosed in the conventional farming area can not occur.

In the following, these two conditions are supposed to be verified. Then, knowing that the bid rents of conventional and direct-selling farmers must equalize at $\bar{x}_s$, we find $\bar{R}_s = \bar{R} - \alpha\psi\lambda_u\zeta_u s(\bar{x}_s, \lambda_u, \lambda_s)$, so that we now have:

$$\varphi_s(x) = \bar{R} + \alpha\psi\lambda_u\zeta_u[s(x, \lambda_u, \lambda_s) - s(\bar{x}_s, \lambda_u, \lambda_s)] \tag{32}$$

Analogously, we know that urban bid rent and direct-selling bid rent must equalize at the urban fringe $\bar{x}_u$. Hence, replacing ζ_u by its value in (32) and equating $\varphi_u(\bar{x}_u)$ to $\varphi_s(\bar{x}_u)$ yields:

$$\bar{R}_u = \frac{\bar{R} + t_u\frac{\lambda_u}{2} + \alpha\psi\lambda_u\frac{\bar{e}_u^\eta - \bar{e}_s^\eta}{S}w_u}{\frac{\alpha\psi\lambda_u}{\delta}\frac{\bar{e}_u^\eta - \bar{e}_s^\eta}{S} + 1} \quad \text{and} \quad \bar{R}_s = \bar{R} - \frac{(\delta w_u - t_u\frac{\lambda_u}{2} - \bar{R})\bar{e}_s^\eta}{\frac{\delta S}{\alpha\psi\lambda_u} + \bar{e}_u^\eta - \bar{e}_s^\eta} \tag{33}$$

From (33), we can note that the entry of a new farmer on direct-selling market leads to an increase in the intercept of the bid land rent function $\bar{r}$ but tends, in the same time, to flatten the function since its slope is decreasing with respect to λ_r^s. As a result, we can show that a rise in direct-selling farmers can either lead to an increase or a decrease of the bid, depending on the location within the region. The explanation of this result is to be found in the variation of the direct-selling profit with respect to the number of varieties; as previously mentioned, a new entrant always leads to a decrease in the market share of all the competitors already engaged in direct-selling. Their operating profit is consequently lower, as a result of a loss in terms of location rent. However, in the same time, the new competitor enters the market with a smaller share, leading to lower the benchmark value to which the profit of all the farmers should equalize at the land market equilibrium $\pi_s(\bar{x}_s, \lambda_u)$. In the end, each farmer can either make a larger or a lower bid, depending on his own loss in operating profit relative to the overall decrease in direct-selling profits.

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

$$\varphi_u(x) = \delta\left(w_u - \zeta_u^m(\lambda_u, \lambda_s) - t_u x\right) \quad \text{and} \quad \varphi_s(x) = \alpha\psi\lambda_u\zeta_u^m(\lambda_u, \lambda_s)\frac{e(t(x), h(x, \lambda_u))^\eta - \bar{e}^\eta}{S(\lambda_u, \lambda_s)} + \bar{R} \tag{34}$$

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

$$\zeta_u^m(\lambda_u, \lambda_s) \equiv \frac{w_u - t_u \frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}}{\frac{\alpha\psi\lambda_u}{\delta} \frac{\bar{e}_u^\eta - \bar{e}_s^\eta}{S(\lambda_u,\lambda_s)} + 1} \tag{35}$$

The direct-selling bid rent follows the spatial variations of $e(t(x), h(x, \lambda_u))$; it is thus decreasing with the distance from the CBD if the effect of the market access cost dominates that of the urban pollution externality, and increasing otherwise. Combining (27) and (34), the equilibrium land rent is finally given by:

$$R^m(x, \lambda_u, \lambda_s) = \begin{cases} \delta\left(w_u - \zeta_u^m(\lambda_u, \lambda_s) - t_u x\right) & \text{if } 0 < x \leq \bar{x}_u \textit{ (urban area)} \\ \alpha\psi\lambda_u\zeta_u^m(\lambda_u, \lambda_s)\dfrac{e(t(x), h(x, \lambda_u))^\eta - \bar{e}^\eta}{S(\lambda_u, \lambda_s)} + \bar{R} & \text{if } \bar{x}_u < x \leq \bar{x}_s \textit{ (d-s farming area)} \\ \bar{R} & \text{if } x > \bar{x}_s \textit{ (conventional farming area)} \end{cases} \tag{36}$$

Appendix B: Market share

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

$$s(x, \lambda_u, \lambda_s) = \frac{e(t(x), h(x, \lambda_u))^\eta}{S(\lambda_u, \lambda_s)} \qquad (0 \leq s(x, \lambda_u, \lambda_s) \leq 1) \tag{37}$$

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

$$S_{\lambda_u}(\lambda_u, \lambda_s) = -2 \times \left[\eta|e_h h_{\lambda_u}| \int_{\bar{x}_u}^{\bar{x}_s} e(t(x), h(x, \lambda_u))^{\eta-1} dx + \frac{\bar{e}_u^\eta - \bar{e}_s^\eta}{2\delta}\right] < 0 \tag{38}$$

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

$$s_{\lambda_s}(x, \lambda_u, \lambda_s) = -\frac{e(t(x), h(x, \lambda_u))^\eta \times e(t(\bar{x}), h(\bar{x}, \lambda_u))^\eta}{S(\lambda_u, \lambda_s)^2} = -s(x, \lambda_u, \lambda_s)\bar{s} < 0 \tag{39}$$

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

Market share and urban pollution. Differentiating $e(h(x, \lambda_u), t(x))$ and $S(\lambda_u, \lambda_s)$ with respect to h yields:

$$\frac{\partial e}{\partial h} = -|e_h| \quad \text{and} \quad S_h(\lambda_u, \lambda_s) = -2\eta|e_h| \int_{\bar{x}_u}^{\bar{x}_s} e(t(x), h(x, \lambda_u))^{\eta-1} dx < 0 \tag{40}$$

As shown by (40), increasing the urban pollution always leads to diminish the value of the productivity coefficient at x – *and consequently the receipts* –, but also the supply-side market potential S. Hence, assessing the overall impact of the urban pollution on the market share at x boils down to a comparison between the effect in this location and that on the whole sector. Indeed, differentiating the market share at x with respect to the pollution level h and rearranging, we have:

$$s_h(x, \lambda_u, \lambda_s) = \eta|e_h| \left[\frac{\int_{\bar{x}_u}^{\bar{x}_s} e(t(x), h(x, \lambda_u))^{\eta-1} dx}{\int_{\bar{x}_u}^{\bar{x}_s} e(t(x), h(x, \lambda_u))^{\eta} dx} - e(t(x), h(x, \lambda_u))^{-1} \right] s(x, \lambda_u, \lambda_s) \quad (41)$$

with $\int_{\bar{x}_u}^{\bar{x}_s} s_h(x, \lambda_u) dx = 0$.
The term in brackets captures the overall pollution intensity effect. More precisely, it compares the *sectoral shortfall rate* $\frac{\int_{\bar{x}_u}^{\bar{x}_s} e(t(x),h(x,\lambda_u))^{\eta-1} dx}{\int_{\bar{x}_u}^{\bar{x}_s} e(t(x),h(x,\lambda_u))^{\eta} dx}$ with the *yield-loss rate* at location x. We derive that the market share of a farmer located at x is positively linked to the urban pollution provided that the *yield-loss rate* at location x is sufficiently low, that is:

$$\frac{1}{e(t(x), h(x, \lambda_u))} < \frac{\int_{\bar{x}_u}^{\bar{x}_s} e(t(x), h(x, \lambda_u))^{\eta-1} dx}{\int_{\bar{x}_u}^{\bar{x}_s} e(t(x), h(x, \lambda_u))^{\eta} dx} \quad (42)$$

Observe finally that when productivity is homogeneous over space, the term in brackets falls to zero, meaning that the urban pollution has no impact on the market share ($s_h = 0$).

Appendix C: Free-entry equilibrium and the urban population size

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

$$\hat{\lambda}_s^*(\lambda_u) = \frac{\alpha\psi\lambda_u}{\delta\bar{R}} \left(\delta w_u - \frac{t_u}{2}\lambda_u - \bar{R} \right) \quad (43)$$

and its derivative with respect to λ_u is:

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

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

and λ_u, and evaluating at the free-entry equilibrium yields:

$$\frac{\partial \pi_s}{\partial \lambda_s}(\lambda_u, \lambda_s^*) = -\frac{\bar{R}^2}{\delta \bar{w}_u}\left[\phi\left(\bar{s}_s + \frac{\eta |e_x(\bar{x}_s)|}{2\bar{e}_s}\right) - \bar{s}_u\right] < 0 \quad \text{and} \tag{45}$$

$$\frac{\partial \pi_s}{\partial \lambda_u}(\lambda_u, \lambda_s^*) = \frac{\bar{R}^2}{\delta \bar{w}_u}\left(\frac{\phi \bar{s}_s - \bar{s}_u}{\lambda_u \bar{s}_s} - \frac{t_u}{2\bar{R}} + \frac{\phi s_{\lambda_u}(\bar{x}_s, \lambda_u, \lambda_s^*) - s_{\lambda_u}(\bar{x}_u, \lambda_u, \lambda_s^*)}{\bar{s}_s}\right) \tag{46}$$

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

$$\frac{\partial \lambda_s^*}{\partial \lambda_u} = \frac{1}{\phi\left(\bar{s}_s + \frac{\eta |e_x(\bar{x}_s)|}{2\bar{e}_s}\right) - \bar{s}_u}\left(\frac{\phi \bar{s}_s - \bar{s}_u}{\lambda_u \bar{s}_s} - \frac{t_u}{2\bar{R}} + \frac{\phi s_{\lambda_u}(\bar{x}_s, \lambda_u, \lambda_s^*) - s_{\lambda_u}(\bar{x}_u, \lambda_u, \lambda_s^*)}{\bar{s}_s}\right) \tag{47}$$

Eq. (47) can be rearranged so as to make $\frac{\partial \hat{\lambda}_s^*}{\partial \lambda_u}$ apparent:

$$\frac{\partial \lambda_s^*}{\partial \lambda_u} = \frac{\phi \bar{s}_s - \bar{s}_u}{\phi\left(\bar{s}_s + \frac{\eta |e_x(\bar{x}_s)|}{2\bar{e}_s}\right) - \bar{s}_u}\left[\frac{\partial \hat{\lambda}_s^*}{\partial \lambda_u} + \frac{\phi s_{\lambda_u}(\bar{x}_s, \lambda_u, \lambda_s^*) - s_{\lambda_u}(\bar{x}_u, \lambda_u, \lambda_s^*)}{(\phi \bar{s}_s - \bar{s}_u)\bar{s}_s}\right] \tag{48}$$

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

$$\frac{\partial s}{\partial \lambda_u}(\bar{x}_u, \lambda_u, \lambda_s^*) \equiv s_{\lambda_u}(\bar{x}_u) = \bar{s}_u\left[\frac{\eta e_x(\bar{x}_u)}{2\delta \bar{e}_u} + \frac{\bar{s}_u - \bar{s}}{\delta} + \eta |e_h h_{\lambda_u}|\left(\xi - \frac{1}{\bar{e}_u}\right)\right] \tag{49}$$

and

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

with the simplifying notation $\xi \equiv \frac{\int_{\bar{x}_u}^{\bar{x}_s} e(t(x), h(x, \lambda_u))^{\eta - 1} dx}{\int_{\bar{x}_u}^{\bar{x}_s} e(t(x), h(x, \lambda_u))^{\eta} dx}$. Then, using (49) and (50), we find:

$$\frac{\phi s_{\lambda_u}(\bar{x}_s) - s_{\lambda_u}(\bar{x}_u)}{(\phi \bar{s}_s - \bar{s}_u)\bar{s}_s} = \frac{\eta}{2\delta}\frac{\phi \bar{e}_s^{\eta-1} e_x(\bar{x}_s) - \bar{e}_u^{\eta-1} e_x(\bar{x}_u)}{(\phi \bar{e}_s^{\eta} - \bar{e}_u^{\eta})\bar{s}_s} + \frac{(\frac{\bar{e}_u}{\bar{e}_s})^{\eta} - 1}{\delta} + \frac{\eta |e_h h_{\lambda_u}|}{\bar{s}_s}\left(\xi - \frac{\phi \bar{e}_s^{\eta-1} - \bar{e}_u^{\eta-1}}{\phi \bar{e}_s^{\eta} - \bar{e}_u^{\eta}}\right) \tag{51}$$

Appendix D: The sectoral shortfall rate

As previously mentioned, $e(t(x), h(x, \lambda_u))^{-1}$ represents the yield-loss factor – *that is the differential between the effective yields and the theoretical yields that would be obtained without externalities*. $e(t(x), h(x, \lambda_u))^{-1}$ can thus also be interpreted as the expected profit-loss factor, which differs from the effective profit-loss factor given by $e(t(x), h(x, \lambda_u))^{-\eta}$ (See Eq.15). The ratio of these two elements gives $e(t(x), h(x, \lambda_u))^{\eta-1}$, 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, $e(t(x), h(x, \lambda_u))^{\eta-1}$ 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 direct-selling market, we obtain the aggregate shortfall factor for the direct-selling sector $\int_{\bar{x}_u}^{\bar{x}_s} e(t(x), h(x, \lambda_u))^{\eta-1} dx$. Finally, reported on the aggregate profit-loss rate $\int_{\bar{x}_u}^{\bar{x}_s} e(t(x), h(x, \lambda_u))^{\eta} dx$, we get:

$$\frac{\int_{\bar{x}_u}^{\bar{x}_s} e(t(x), h(x, \lambda_u))^{\eta-1} dx}{\int_{\bar{x}_u}^{\bar{x}_s} e(t(x), h(x, \lambda_u))^{\eta} dx} > 1 \quad (52)$$

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*.

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