Feeding the Cities and Greenhouse Gas Emissions. Beyond the Food Miles Approach

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Abstract

In this paper, we study the impact of urbanization on the location of agricultural production and the GHG emissions related to transportation activities. We develop an economic geography model where the location of agricultural activities and urban population are endogenous. We show that increasing agricultural yields induce the spatial concentration of agricultural production in the least urbanized region if agricultural transport costs are relatively low and in the most urbanized region otherwise. In addition, interregional trade in agricultural commodities is desirable to reduce GHG emissions, except when urban population is equally split between cities. However, the market may induce too much agglomeration of agricultural production when yields are high and when collection costs are low.

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1 Introduction

More than half of the world population lives in cities. This share is expected to keep rising in both developed and developing countries, reaching 84% in 2050 in developed countries and about 65% in Africa and Asia (United Nations, 2010). This rising trend results in an inter-urban concentration of population and urban sprawl. Urban expansion has two major consequences for the sustainability of food systems. First, increasing quantities of food have to be brought into cities. This involves larger volumes of transported agricultural products and more energy used in the process. Second, urbanization increases the competition for land between residential, industrial, and agricultural uses. As an illustration, residential land use in the US grew 47.5% between 1976 and 1992, while population only grew 17.8% (Overman, Puga and Turner, 2008).

Feeding the cities in a sustainable way has emerged as a growing concern for public authorities. Relocation of agricultural production in the highly populated regions is sometimes advocated as one means of enhancing food security and lowering the negative environmental impacts of food production. The latter argument usually revolves around the “food miles” concept (Pretty et al., 2005): reducing the distance food is transported from the producer to the consumer may contribute to the mitigation of transport-related greenhouse gas (GHG) emissions.

In the present paper, we argue that important economic mechanisms are overlooked when focusing solely on 'food-miles'. The location of agricultural activities endogenously depends on equilibrium land prices, which are affected by transport costs and by the competition between agricultural and other competing land uses (housing, industry). In addition, the market structure has an impact on the endogenous location choices in terms of housing and industry, which in turn determines the spatial distribution of agricultural activities. When accounting for these effects, the relationships between the location of agricultural production and GHG emissions appear much more complex than what is suggested by the food-miles approach.

The objective of this paper is to lay the groundwork for an analytical treatment of the trade-offs between curbing GHG emissions stemming from intra- or inter- regional transport. The model extends that proposed by Gaigné et al. (2011) by including an agricultural sector in which production is endogenously determined. The differentials across space in the pollution caused by agricultural production itself and in land productivity are left aside. Although these dimensions are admittedly important in the relation between location of agricultural activities and GHG emissions, this allows us to focus on the important economic trade-offs at play in the transport-related emissions.

Even without accounting for these two dimensions, we exhibit cases where food can be sourced from remote locations whilst reducing total transport-related GHG emissions. More generally, we show that increasing agricultural yields induces a spatial concentration of agricultural production in the least urbanized region if agricultural transport costs are low and in the most urbanized region otherwise. Nevertheless, interregional trade in agricultural commodities is desirable to reduce GHG emissions, except when urban population is equally split between cities. In addition, the market may induce too much agglomeration of agricultural production when yields are high and when agricultural transport costs are low.

This paper is outlined as follows. The next section presents the analytical framework. In section 3, we examine the link between the location of agricultural activities and GHG emissions. Section 4 extends the analysis by studying firms' location choices. We finally conclude in section 4, discussing the implications of agents' spatial location on GHG emissions stemming from agricultural freight.

2 The Model

(i) The spatial structure Consider an economy with two regions, indexed by $r = 1, 2$, $L > 0$ mobile workers and $A > 0$ farmers, two sectors (the agricultural sector and the manufacturing sector, labeled $i = a, m$), and three primary goods: labor, land, and the numéraire, which is traded costlessly between the two regions.

Regions 1 and 2 are separated from one another by a distance of ν. Each region is formally described by a one-dimensional space. It can accommodate a city where firms and workers are located and rural areas where farmers live and produce. Whenever a city is formed, it has a central business district (CBD) located at $x = 0$ where region-r firms are set up.[1] Without loss of generality, we focus on the right-hand side of the region, the left-hand side being perfectly symmetrical. Distances and locations are expressed by the same variable x measured from the CBD. Our purpose being to highlight the interactions between the transport sector and the location of activities, we assume that the supply of natural amenities is the same in both cities.

Urban inhabitants consume a residential plot of fixed size $s > 0$, regardless of their location. For simplicity, we assume s to be normalized to unity. Denoting by L_r the urban population residing in city r (with $L_1 + L_2 = L$), the right endpoint of this city is then given by

$$\bar{x}_r = \frac{L_r}{2}.$$

In each region, the rural population settles at the periphery of the urban area. Every rural dweller uses $1/\mu$ units of land to produce the agricultural good with $1/\mu > 1$ (or, equivalently, $1 - \mu > 0$). The right endpoint of region r is then given by

$$x_a^r = \frac{L_r}{2} + \frac{A_r}{2\mu}$$

where A_r stands for the rural population located in region r.

(ii) Consumers Preferences are identical across consumers and given by the utility function

$$U_r = \left(\alpha_a - \beta_a \frac{q_a^r}{2}\right) q_a^r + \left(\alpha_m - \beta_m \frac{q_m^r}{2}\right) q_m^r + q_0 \tag{1}$$

where q_i^r $i = a, m$ are respectively the consumption of the agricultural good and the manufactured good and q_0 the consumption of the numéraire. The unit of the manufactured good is chosen for $a = 1$ to hold.

Each urban worker is endowed with one unit of labor and $\bar{q}_0 > 0$ units of the numéraire. The initial endowment $\bar{q}_0$ is supposed to be large enough for the individual consumption of the numéraire to be strictly positive at the equilibrium outcome.[2] Urban dwellers commute to the CBD and pay a unit transport cost $t > 0$, so that an individual located at $x > 0$ bears a commuting cost equal to tx. Hence, the budget constraint faced by a urban household residing at x in region r is given by

$$q_a^r p_a^r + q_m^r p_m^r + q_0 + R_r(x) + tx = w_r + \bar{q}_0 \tag{2}$$

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[1] See the survey by Duranton and Puga (2004) for the reasons explaining the existence of a CBD.

[2] For simplicity, we assume that land is owned by absentee landlords.

where p_i^r is the price of the i-good, $R_r(x)$ is the land rent at x, and w_r the wage paid by firms in region r's CBD. Within each region, a urban worker chooses his location so as to maximize his utility (1) under the budget constraint (2). Because of the fixed lot size assumption, the value of the consumption of the nonspatial goods $q_a^r p_a^r + q_m^r p_m^r + q_0$ at the residential equilibrium is the same regardless of the worker's location. The opportunity cost of land being equal to $R_a^r = 0$, the equilibrium land rent can be written as follows:

$$R_r^*(x) = t\left(\frac{L_r}{2} - x\right) \qquad \text{for } x < \bar{x}_r. \tag{3}$$

Utility maximization leads to the inverse demand for good m, $p_m^r = \alpha_m - \beta_m q_m^r$, so that region r's inverse demand for this good is given by

$$p_m^r = \min\left\{\alpha_m - \beta_m Q_m^r/(L_r + A_r), 0\right\} \tag{4}$$

where Q_m^r is the total quantity of the manufactured good sold in region r. Similarly, utility maximization leads to the inverse demand for good a, $p_a = \alpha_a - \beta_a q_a$, so that region r's inverse demand for this good is

$$p_a = \min\left\{\alpha_a - \beta_a Q_a^r/(L_r + A_r), 0\right\} \tag{5}$$

where Q_a^r is the total quantity of the agricultural good sold in region r.

(iii) The agricultural sector. In the agricultural sector, farms produce at constant returns to scale and are price-takers. The mass of labor working in the agricultural sector is given by A. We assume that each farm produces one unit of agricultural good, using one unit of labor A and $1/\mu$ units of land. μ thus captures the agricultural yields. The market clearing condition for the agricultural good is such that $A = Q_a$, with $Q_a = (\alpha_a - p_a)(L + A)/\beta_a$ so that

$$p_a^* = \alpha_a - \frac{\beta_a A}{L + A}$$

Observe that, because of the perfect competition condition, p_a^* is common to all farmers, regardless of the region where their activity takes place. Thus, we can straight away notice that the agricultural price will not play any role in the farmers' location choice.

In order to sell their produce, farmers have to convey their goods to the CBD which induces transportation costs. The operating profits of a region r farm are consequently given by

$$\pi_a^r(x) = p_a^* - \frac{R_a^{r*}(x)}{\mu} - w_a^r(x) - T_a(x)$$

where $R_a^{r*}(x)$ represents the equilibrium land rent paid by a farm located at x and T_a the total transport cost incurred by the farmer. The total freight cost includes the cost of shipping from the farmer to the elevator located at x_r^c and the average cost of transport from the elevator to the final markets so that

$$T_a = t_a\left|x - x_r^c\right| + t_a Q_r^a x_r^c / A_r$$

where t_a is the unit cost of agricultural transport. Because $Q_r^a = A_r$, we have $T_a = t_a\left|x - x_r^c\right| + t_a x_r^c$. We assume that $x_r^c = \bar{x}_r + (x_a^r - \bar{x}_r)/2$, that is the elevator is located in the middle of each agricultural area. Note that, if the transport demand for agricultural commodities at the farm level is inelastic, the regional transport demand for agricultural products varies with the freight price (t_a).

Because each farm consumes $1/\mu$ units of land, $R_a^{r*}(x)$ is equal to

$$R_a^{r*}(x) = \mu t_a\left(\frac{A_r}{4\mu} - \left|x - x_r^c\right|\right) \tag{6}$$

Finally, the equilibrium wage rate is determined by a bidding process in which farms compete for labor by offering higher wage until no farm can profitably enter the market. Hence, operating profits are completely absorbed by the wage bill and the equilibrium wage rate in region r must satisfy the condition $\pi_a^r = 0$, which yields

$$w_a^{r*} = p_a^* - t_a \left(\frac{A_r}{2\mu} + \frac{L_r}{2} \right). \tag{7}$$

Note that according to (7), agricultural wages differ across regions; in particular, the more the region r will be extended, the more the cost of agricultural transportation will be high, which implies the equilibrium wage w_a^{r*} to be cut down. Moreover, the total agricultural production is exogenous and, thus, does not depend on the spatial distribution of farmers. In other words, the GHG emissions related to agricultural production activity is supposed to be constant regardless of its location.

(iv) The manufacturing sector. Firms of the manufacturing sector produce a homogeneous good under imperfect competition. They locate in a CBD and are assumed to use no land. Moreover, producing q units of the manufactured good requires $\phi > 0$ units of labor. Free entry involves that there are $n = L/\phi$ (up to the integer problem) oligopolistic firms competing in quantity. Without loss of generality, the unit of labor is chosen for ϕ to be equal to 1, thus implying $n = L$.

The manufactured good can be shipped between regions at the cost of $\tau > 0$ units of the numéraire. Because they are spatially separated, the two regional markets are supposed to be segmented. This means that each firm chooses a specific quantity to be sold on each market. Let q_{rs} be the quantity of the manufactured good that a region r firm sells in city $s = 1, 2$. The operating profits of a region r firm are then given by

$$\pi_r = q_{rr} p_m^r + q_{rs}(p_m^s - \tau\nu)$$

with $s \neq r$. The equilibrium quantities sold by a region r firm are such that $q_{rr}^* = (L_r + A_r) p_m^r / \beta_m$ and $q_{rs}^* = (L_s + A_s)(p_m^{s*} - \tau\nu)/\beta_m$. The market clearing condition for the manufactured good in each region is such that $Q_r^m(p_m^r) = n_r q_{rr}(p_m^r) + n_s q_{sr}(p_m^r)$, where n_r is the number of firms located in region r (with $n_1 + n_2 = n$). Hence, the equilibrium price in region r is

$$p_m^{r*} = \frac{\alpha_m + \tau\nu n_s}{n+1}. \tag{8}$$

Trade between regions arises at the equilibrium prices regardless of the intercity distribution of firms if and only if

$$\tau < \tau_{trade} \equiv \frac{\alpha_m}{(n+1)\nu} \tag{9}$$

a condition which is supposed to hold throughout the paper.

Finally, the profits of a firm settled in region r are given by $\Pi_r = \pi_r - w_r$. As in the agricultural sector, urban labor markets are local and the equilibrium wage is determined by a bidding process in which firms compete for workers by offering them higher wages until no firm can profitably enter the market. Hence, the equilibrium wage rate in region r must satisfy the condition $\Pi_r = 0$, which yields

$$w_r^* = \pi_r^* = (p_m^{r*})^2 \frac{(L_r + A_r)}{\beta_m} + (p_m^{s*} - \tau\nu)^2 \frac{(L_s + A_s)}{\beta_m}. \tag{10}$$

3 Agricultural location and urbanization: regional specialization vs agglomeration

The following analysis aims to define conditions under which the market outcome corresponds to an optimal spatial distribution of farmers - in the sense that GHG emissions are minimized. In this section, we only focus on the agricultural location; we first assume that the geographical distribution of urban workers is exogenous, so that farmers make their decision conditional on the location of manufacturing activity. We will respectively denote by λ and λ_a the fraction of urban and rural populations settled in region 1. Without loss of generality, we assume that $\lambda \geq 1/2$ (because the regions are symmetric *ex ante*).

3.1 Spatial equilibrium of the agricultural production

Indirect utility of a region r farmer is given by

$$V_a^r(\lambda, \lambda_a) = w_a^{r*} + S_m^{r*} + S_a^{r*} \tag{11}$$

where S_i^{r*} is the consumer surplus evaluated at the equilibrium prices

$$S_m^{r*} + S_a^{r*} = \frac{L^2(\alpha_m - \tau\nu\lambda_s)^2}{2\beta_m(1+L)^2} + \frac{\beta_a}{2}\left(\frac{A}{A+L}\right)^2 \tag{12}$$

with $\lambda_s + \lambda_r = 1$. Farmers settle in the region that provides the highest indirect utility. They choose a place to live in by weighing the costs and the benefits associated to each location.

Let $\Delta V_a(\lambda, \lambda_a)$ be the utility differential. $\Delta V_a(\lambda, \lambda_a) \equiv V_a^1(\lambda, \lambda_a) - V_a^2(\lambda, \lambda_a)$. An equilibrium arises at $0 < \lambda_a^* < 1$ when the utility differential $\Delta V_a(\lambda, \lambda_a^*) = 0$ (interior equilibrium), or at $\lambda_a^* = 1$ when $\Delta V_a(\lambda, 1) \geq 0$ (corner equilibrium). An interior equilibrium is stable if and only if the slope of the indirect utility differential ΔV_a is strictly negative in the neighborhood of the equilibrium, i.e., $\partial \Delta V_a(\lambda, \lambda_a)/\partial \lambda_a < 0$ at λ_a^*. Whenever it exists, an agglomerated equilibrium is stable.

By replacing w_a^{r*}, S_m^{r*} and S_a^{r*} by their expression, we get the utility differential:

$$\Delta V_a(\lambda, \lambda_a) \equiv \frac{1}{2}\left[\frac{L^2(2\lambda - 1)(2\alpha_m - \tau\nu)\tau\nu}{(1+L)^2\beta_m} + Lt_a(1-2\lambda) + \frac{A(1-2\lambda_a)t_a}{\mu}\right] \tag{13}$$

The above expression reveals that ΔV_a decreases with λ_a. Thus, the interior equilibrium is always stable and takes the following form:

$$\lambda_a^*(\lambda) = \frac{1}{2} + \left(\lambda - \frac{1}{2}\right)\left(\frac{\bar{t}_a}{t_a} - 1\right)\frac{L}{A}\mu \tag{14}$$

where

$$\bar{t}_a \equiv \frac{L\tau\nu(2\alpha_m - \tau\nu)}{\beta_m(1+L)^2}$$

with $\mathrm{d}\bar{t}_a/\mathrm{d}L < 0$ and $\mathrm{d}\bar{t}_a/\mathrm{d}\tau > 0$ since (9) holds.

The impact of urbanization on agricultural production location. From Equation (14), we can first clarify the relation between urbanization and the location of agricultural estates. Clearly, the sign of $\mathrm{d}\lambda_a^*(\lambda)/\mathrm{d}\lambda$ depends on the term $(\bar{t}_a/t_a - 1)$. The direction of migration flows is uniquely determined by this term. For instance, when τ is low and/or L high, $\bar{t}_a$ is small and $(\bar{t}_a/t_a - 1)$ is strictly negative. As a result, λ_a and λ vary in opposite directions, suggesting that the agricultural production tends to locate in the least urbanized region.

This sectoral separation can easily be explained: for small values of τ, the difference between regional prices is small. As a consequence, the incentive to move to the region where manufactured goods used to be cheaper vanishes. Therefore, farmers simply base their location decision according to the agricultural wage or equivalently, the intra-regional collection cost (T_a). Since T_a increases with the size of the urban area, farmers choose to settle in the least crowded region, i.e. the region where the distance from the CBD is the shortest. A direct result of such a spatial organization is that the most urbanized region has to import agricultural goods ($\lambda > \lambda_a$).

By contrast, when the economy is characterized by a relatively small urban population (L low) and a high manufacturing transport cost (τ), the agricultural production settles mainly in the most urbanized region. In this case, parameter $\bar{t}_a$ is high, implying that $(\bar{t}_a/t_a - 1)$ is positive. When shipping goods from one region to the other is costly, foreign firms can hardly compete with the domestic ones on local markets. Hence, domestic prices depend primarily on the intensity of the local competition, and rural households have an incentive to move to the region where the manufactured goods are cheaper. Moreover, in this spatial configuration, the most urban-crowded region may be either importing or exporting, depending on the value of parameters A and μ.

Proposition 3.1 *Agglomeration of agricultural production occurs in the most urbanized region if and only if the non-agricultural population is small enough or interregional transport cost is large enough. Otherwise, agricultural production takes place mainly in the least urbanized region.*

The impact of t_a and μ on the spatial concentration of agricultural production. Equation (14) also enables to specify conditions under which agricultural agglomeration occurs[3]. The values of the parameters t_a and μ determine the strength of the migration flow, and therefore the degree of dispersion of farmers.

A high value of the unit cost of agricultural collection (t_a) restrains the agglomeration process when $\bar{t}_a$ is also high. In such an event, we previously showed that rural dwellers mainly settle in the most urbanized region as the price of the manufactured good is lower. However, this location choice provides them plots that are relatively far from the CBD as the urban area is wide. Yet, when t_a is high, farmers are more sensitive to their intra-regional location because their wage falls much more sharply with the distance that separates their plot of land from the central market. Consequently, migration flows to the most urbanized region are limited and agricultural production tends to disperse across space. By contrast, when $\bar{t}_a$ is low, high values of t_a foster agricultural concentration since, in this case, agglomeration takes place in the region hosting the smallest urban population. Thus, stable patterns characterized by a sectoral separation of the economy occur and may even lead to a configuration of regional economic specialization for extreme values of t_a.

Concerning the agricultural yields, it is readily verified that agglomeration is driven by large values of μ. High yields are equivalent to low land requirements. Hence, from the perspective of farmers, a large value of μ involves that the size of their estate is relatively condensed and consequently, that the cost they have to pay to settle in a region remains low ($R_a^r(x)/\mu$). Lastly, equation (14) indicates that the less the agricultural activity is land consuming (μ high), the more the degree of agglomeration of the rural population is important. On the contrary, a significant need in land encourages rural households to disperse so as to reduce the cost of the rent.

Our main results are summarized in the following proposition:

Proposition 3.2 *Increasing yields (μ) and decreasing collection cost (t_a) favor the spatial concentration of agricultural production in the least urbanized region when the share of urban population in the economy is high enough and in the most urbanized region otherwise.*

3.2 Spatial patterns and the environment

We now include the GHG emissions due to the transportation of agricultural goods. We distinguish between the inter- and intra-regional transport of agricultural goods.

The purpose of the further analysis is to determine the spatial patterns that would be best suited to curb GHG emissions stemming from transport of agricultural goods. In order to make the discussion clearer, we proceed in two steps. We start by exploring the impact of farms' distribution

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[3] Giving our framework, agglomeration (or spatial concentration) of agricultural production means $\lambda_a^* \to 1$ or $\lambda_a^* \to 0$ while dispersion is equivalent to $\lambda_a^* \to 1/2$.

on each GHG emissions flow (due to inter- and intra-regional transportation). We account for these two flows simultaneously in a second step.

(i) Inter regional transport of agricultural goods (T_a) The first flow we consider refers to trade in agricultural products between the two regions. The sector being treated as operating in perfect competition[4], flows of agricultural goods are consequently unidirectional; everything happens as if the region that has an excess of agricultural supply exported its surplus to the neighboring region –which, by definition, is short of agricultural goods– in order to bridge the gap between local supply and demand.

The sum of trade flows T_a is given by $\max\{Q_a^1 - A_1, Q_a^2 - A_2\}$ or, equivalently,

$$T_a(\lambda, \lambda_a) = \begin{cases} T_a^1(\lambda) = \dfrac{(\lambda - \lambda_a)AL}{L+A} & \text{if } \lambda > \lambda_a \\ T_a^2(\lambda) = \dfrac{(\lambda_a - \lambda)AL}{L+A} & \text{if } \lambda < \lambda_a \end{cases} \tag{15}$$

Clearly, $T_a(\lambda, \lambda_a)$ is minimized when the two regional populations are qualitatively identical (i.e. $\lambda = \lambda_a$). In this case, food in both regions is locally produced and there is no trade in agricultural products.

(ii) Intra regional transport of agricultural goods (D_a) The second flow refers to the transportation of agricultural goods within each region, ie from the farms' gate to the central market located in the CBD. In each region, the route is made up of a suburban area *–which is more or less long according to the location of farmers within this area–* and the entire urban area ($\bar{x}_r$). The sum of distance traveled by agricultural commodities within regions is given by:

$$D_a(\lambda, \lambda_a) = \sum_r 2\left[\int_{\bar{x}_r}^{x_c^r} (x - \bar{x}_r)\mathrm{d}x + \int_{x_c^r}^{x_a^r} (x_r^a - x)\mathrm{d}x + \frac{A_r}{2}x_r^c\right] = \sum_r \left[\frac{A_r^2}{4\mu}\left(1 + \frac{1}{2\mu}\right) + \frac{A_r L_r}{2}\right]$$

$D_a(\lambda, \lambda_a)$ increases with the distance that rural dwellers have to cover to get to the city center.

(iii) The environmental impact of agricultural goods transportation The total GHG emissions stemming from agricultural goods transportation are given by:

$$E_{agr}(\lambda, \lambda_a) = e_T \nu T_a(\lambda, \lambda_a) + e_D D_a(\lambda, \lambda_a)$$

where e_T is the amount of GHG emissions generated by one unit of distance traveled by a good shipped to the neighboring region, and e_D represents the amount of GHG emissions generated by one unit of distance traveled by an agricultural good within a region. The value of these parameters depends on the technology used for transportation.

$E_{agr}(\lambda, \lambda_a)$ describes a convex parabola in λ_a. As a consequence, the function is minimized when the derivative $\partial E_{agr}(\lambda, \lambda_a)/\partial \lambda_a$ is set to zero. Let us denote by λ_a^e the share of the rural population settled in region 1 that allows to minimize the emissions. λ_a^e can take two different forms depending on whether region 1 is importing or exporting agricultural goods:

$$\lambda_a^e(\lambda) = \begin{cases} \frac{1}{2} + \left(\frac{1}{2} - \lambda\right) \frac{L\mu(1+2\mu)}{A} + \frac{e_T \nu L \mu^2}{e_D A(A+L)} & \text{if region 1 imports A} \\ \frac{1}{2} + \left(\frac{1}{2} - \lambda\right) \frac{L\mu(1+2\mu)}{A} - \frac{e_T \nu L \mu^2}{e_D A(A+L)} & \text{if region 1 exports A} \\ \frac{1}{2} + \left(\frac{1}{2} - \lambda\right) \frac{L\mu(1+2\mu)}{A} & \text{if no agricultural inter-region trade} \end{cases} \tag{16}$$

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[4] Agricultural market is a common market where supplies from the two regions gather to balance out the overall demand.

The above expression has been written so that each component that helps to qualify the optimal spatial pattern[5] appears separately. Hence, referring to (16), we can first notice that the location of urban activities has an impact on the environmentally recommended agricultural distribution. More precisely, it appears that the benefit of the agricultural agglomeration in the least crowded region rises with the growth of the largest city. Indeed, $L\mu(1+2\mu)/A$ being positive, an increasing value of λ entails a decline of the agricultural production share located in region 1. Moreover, one can add that the environmental interest to foster both sectoral separation and agricultural concentration is all the more great when the urban population is particularly large compared to the rural one.

Proposition 3.3 *For the sake of emissions, the spatial concentration of agricultural production in the least urbanized region is more and more desirable when the size of the larger city increases, regardless of urban population and transport cost.*

Focusing on parameter μ, Equation(16) reveals that, when agriculture is relatively intensive and region 1 is exporting, the dispersion of farmers is required to curb the GHG emissions. In this case, the agricultural production is too much concentrated in the most urban-crowded region, so that the smallest one can not produce enough commodities to feed its inhabitants. Region 2 must consequently import goods from region 1. Yet, the transportation of agricultural commodities between regions generates GHG emissions that could be avoid by a partial relocation of the production. Here, the relocation would consist in enlarging the share of farmers settled in region 2 in order to bridge the gap between local supply and demand (i.e. $\lambda_a \simeq \lambda$).

In the event that region 1 is importing, the impact of increasing yields is more ambiguous. On the one hand, high values of μ reinforce the ecological interest to gather agricultural estates in the least urbanized region. Indeed, as farms take up little land, the concentration of agricultural production within the smallest region allows to reduce the intra-regional average mileage, without inducing a substantial spatial expansion. On the other hand, region 1 is known to be the most urbanized and holds in consequence, the largest share of the final demand for agricultural goods. Thus, there is also an environmental interest to maintain some agriculture production in this region, as a complete sectoral separation would strongly increase trade emissions by exacerbating the imbalance between local supply and demand.

Lastly, the conditions under which encouraging local consumption and relocation is environmentally beneficial are determined by the GHG emissions balances of inter-regional and intra-regional transportation. Hence, supposing that shipping one unit of agricultural good from one region to the other generates more greenhouse gases than transporting it from the rural area to the CBD ($e_T\nu/e_D$ high), the environmental benefit in relocating production is large. In this case, switching from a global to a local supply chain allows to curb the emissions. On the contrary, if transportation between regions is less GHG emitter than intra-regional collection, the benefit of relocation fades. It is then preferable to disperse the agricultural production and retain - or even enhance - interregional trade.

Proposition 3.4 *For the sake of emissions, the dispersion of agricultural production is more desirable when yields (μ) increase if the region hosting the larger city exports agricultural commodities. By contrast, if the most urbanized region is importing, agricultural agglomeration is recommended when yields (μ) increase provided that $e_T\nu/e_D$ is high.*

3.3 Market outcome vs ecological outcome

We are now equipped to compare the optimal location of agricultural production with the spatial equilibrium. To do so, we must take into account three configurations relatively to agricultural

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[5] Note that the term optimal refers to the situation where GHG emissions are minimized.

interregional trade: (i) no interregional trade; (ii) region 1 imports; and (iii) region 1 exports. Assessing for each case the difference between the spatial equilibrium (λ_a^*) and the optimal distribution (λ_a^e), we get:

$$\lambda_a^*(\lambda) - \lambda_a^e(\lambda) = \begin{cases} \left(\lambda - \frac{1}{2}\right) \frac{L}{A}\mu \left(\frac{\bar{t}_a}{t_a} + 2\mu\right) \geq 0 & \text{if there is no interregional trade} \\ \left(\lambda - \frac{1}{2}\right) \frac{L}{A}\mu \left(\frac{\bar{t}_a}{t_a} + 2\mu\right) - \frac{e_T \nu L \mu^2}{e_D A(A+L)} & \text{if region 1 imports} \\ \left(\lambda - \frac{1}{2}\right) \frac{L}{A}\mu \left(\frac{\bar{t}_a}{t_a} + 2\mu\right) + \frac{e_T \nu L \mu^2}{e_D A(A+L)} > 0 & \text{if region 1 exports} \end{cases} \tag{17}$$

(i) The first expression of (17) reveals that when the market mechanisms lead to a configuration without interregional trade in agricultural products, the situation is not optimal for a sake of emissions, except for $\lambda = 1/2$. Thus, in this case, more dispersion of agricultural production (and thus more interregional trade) is needed to reduce GHG emissions.

(ii) If the region hosting the larger city imports ($\lambda > \lambda_a^*$), it appears that high t_a makes more likely the fact that the market yields too dispersion. In addition, there is too much dispersion with high values of μ provided that $e_T \nu / e_D$ is high enough. When the agricultural yields are high, total infra-regional transport of agricultural products decreases so that agricultural agglomeration within a region is more sustainable than dispersion. In addition, if the distance between regions are high (ν) or if the interregional transport mode induces more emissions by unit shipped than the infra-regional transport mode (e_T / e_D high), then the agglomeration of agricultural production must take place in the most urbanized region. However, with very low values of agricultural yield (μ close to zero), the market mechanisms leads to the optimal spatial organization in terms of emission. Indeed, in this case, full dispersion of agricultural production occurs.

(iii) Finally, if the region hosting the larger city imports ($\lambda_a^* > \lambda \geq 1/2$), then market induces too much agglomeration in the most urbanized region when total urban population is relatively high (L/A high) and agricultural yields are low.

The following proposition summarizes our main findings:

Proposition 3.5 *Interregional trade in agricultural commodities is desirable to reduce GHG emissions, except when urban population is equally split between cities. The market yields too agglomeration of agricultural production when yields are high provided that $e_T \nu / e_D$ is low and when the unit cost of collection is low.*

4 Spatial shaping and GHG emissions from transportation

So far, we assumed that the spatial distribution of urban workers was given and fixed. This made the analysis more tractable and enabled us to focus solely on the agricultural sector. Significant results have been highlighted and might have been missed if we had not proceeded so.

However, such an assumption is hardly tenable. The discussion we made denied all the intersectoral relationships and can therefore only give partial - if not biased - teachings. In fact, the location decisions of urban and rural populations are necessarily related to each other. Indeed, from the perspective of firms, agricultural location is crucial since rural households account for potential consumers. Hence, firms will always look at the size of the domestic demand before choosing the region to settle.

This observation ensures that the above assumption does not hold in practice. Consequently, we propose to relax the hypothesis in the remainder of this paper in order to make the analysis more realistic. In the following, we will successively determine the locational equilibrium of the manufacturing activity and highlight the link between spatial organization of the economy as a whole and GHG emissions due to transportation of agricultural commodities.

The indirect utility of a urban worker living in region r is given by

$$V_r(\lambda, \lambda_a) = S_m^{r*} + S_a^{r*} + w_r^* - UC_r + \bar{q}_0 \tag{18}$$

where UC_r are the urban costs borne by this worker. Using (3), it is readily verified that

$$UC_r \equiv R_r^* + tx = \frac{tL_r}{2}. \tag{19}$$

As for the rural population, urban households residing in region r have an incentive to migrate to region s if the level of the utility they would receive in s is higher than in r. Thus, the migration process can be described by the utility differential $\Delta V(\lambda, \lambda_a^*) \equiv V_1(\lambda, \lambda_a^*) - V_2(\lambda, \lambda_a^*)$. Replacing each term by its expression and substituting λ_a by its equilibrium expression (14), we have:

$$\Delta V(\lambda, \lambda_a^*) = \Delta V(\lambda) = L\left(\lambda - \frac{1}{2}\right)(\bar{t} - t) \tag{20}$$

where

$$\bar{t} \equiv \frac{[2(2+3L)\alpha_m - (2+5L+2L^2)\nu\tau]\nu\tau}{(1+L)^2\beta_m} + \frac{2A\nu^2\tau^2}{(1+L)\beta_m} + \frac{2\mu(1+L)\bar{t}_a}{L}\left(\frac{\bar{t}_a}{t_a} - 1\right)$$

According to (20), $\Delta V(\lambda)$ can be either decreasing or increasing depending on the sign of $(\bar{t} - t)$. Once again, the value of the transport cost determines the stability of the locational equilibrium. Thus, for high values of t ($t > \bar{t}$), the only stable equilibrium is the symmetrical dispersion of urban workers. Referring to (19), urban costs rise with the value of t. As a consequence, when commuting is expensive, urban costs become so high that they can not be offset by any surplus enhancement. In contrast, for low values of t ($t < \bar{t}$), the urban population tends to concentrate, so that an agglomeration pattern occurs. In this case, the low cost allows town residents to gather in a unique region in order to enjoy greater consumption surplus, without having to suffer from high urban costs.

Knowing how urban households choose their location, we can finally replace λ in the expression of λ_a^* in order to define the overall spatial patterns. Hence, we find that the economic activity can be organized according to the two following schemes.

A first pattern consists in a symmetrical dispersion of both the agricultural production and the manufacturing activity ($\lambda^* = \lambda_a^* = 1/2$). This configuration appears when transport within the regional area is costly; urban and rural residents are extremely sensitive to their distance from the center and tend to locate in the least crowded region in order to reduce their transport costs.

The second pattern we may observe involves urban concentration and agricultural dispersion ($\lambda^* = 1$ and $\lambda_a^* = \frac{1}{2} + \frac{L\mu(\bar{t}_a - t_a)}{2At_a}$). In this case, the cost of urban travels is low enough to allow manufacturing workers to agglomerate in a single region ($t < \bar{t}$). Regarding the agricultural location, the level of the collection cost t_a specifies how farmers distribute themselves across space. As the above expression shows, if delivering agricultural goods to the CBD is costly ($t_a > \bar{t}_a$), the production tends to concentrate in the deserted region, so that we get a spatial pattern of economic specialization. On the contrary, if the collection cost is low, a spatial pattern of economic agglomeration appears as rural dwellers are quite likely to settle in the periphery of the urbanized region.

Using the results obtained in Section 3.3, we have $\lambda_a^* = \lambda_a^e = 1/2$ when $t > \bar{t}$ and

$$\lambda_a^* - \lambda_a^e = \frac{L}{A}\mu\left(\frac{\bar{t}_a}{2t_a} + \mu - \frac{e_T\nu\mu}{e_D(A+L)}\right) \text{ when } t < \bar{t}$$

To summarize,

Proposition 4.1 *Assume that the location of urban population is endogenous. If commuting costs are high enough, then the market leads to the spatial distribution of agricultural production minimizing GHG emissions. If commuting costs are low enough, then there is too much agglomeration of agricultural production in the most urbanized region provided that collection costs of agricultural products are low.*

5 Conclusion

In this paper, we have focused on the relationship between the location of agricultural production and GHG emissions due to transportation of agricultural products. The analytical framework used in this paper allows to account for endogenous location of agricultural activities, the trade-offs between competing land uses (residential, industrial, and agricultural), and the relationships between spatial patterns and transport-related emissions.

We analytically highlighted the fact that land productivity affect significantly the location of agricultural production and is crucial to determine the optimal spatial pattern. When agriculture is relatively intensive, production tends to agglomerate in the most urban-crowded region if collection costs are negligible (t_a low), and in the smallest region otherwise. Moreover, when trade accounts for a majority share in the overall balance of GHG emissions, we showed that, from an environmental standpoint, the concentration of farmers within the region hosting the largest city is all the more advisable that this region faces a shortage in agricultural commodities. In addition, market forces may entail an excess of agricultural agglomeration when yields are high or when collection costs are low. In such a situation, the relocation of some of the agricultural production and the development of interregional trade would contribute to partially absorb market imperfections.

This work could be extended in several directions. Including emissions from manufactured goods shipments, the agricultural production itself and land use change would enrich the analysis of the environmental consequences of the spatial organization of the economy. Another possible direction is to relax the assumption of homogeneous land productivity and emission factors across regions. These are left for further research.

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