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Spatial trends of manufacturing – a Von Thünen - Mills approach

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Abstract: We use a location model due to VON THÜNEN (1826) and MILLS (1970; 1972, chapter 5) to determine the patterns of the spatial distribution of manufacturing. In a homogeneous space organized around an activity center (a "Town"), a set of competitive firms produce two complementary commodities: product 1 is a consumer good and product 2, an intermediate good. Firms in both vertically related stages use land and downstream producers of commodity 1 use also product 2 as an input. The productive activity takes place under fixed proportions and the economy is competitive.

We further introduce increasing returns, which are **external to the firm** and derive from a fixed input (a "machine") that is shared by all manufacturers. We presuppose that such a "machine" is supplied by the set of landowners if the fixed cost is covered by the increase in total land rent (or capitalized value of land) related with its installation.

This model can be interpreted in two different ways. Either the intermediate good is viewed as a raw material that is produced by farmers and successively "refined" by a manufacturer, who uses a "mill" or "distillery" for that purpose, or it can stand for "labor" supplied by households with residential land. The economic results are the same in both cases.

The model shows that the decentralization of manufacturing and its spatial integration with primary production or workers' residences takes place more likely in industries that are labor-intensive (or show high "refining rates" of raw materials) and relatively small fixed costs requirements. The factories that relocate away from the activity center will likely stay in areas at an **intermediate** distance rather than in remote territories since they would then face too high transport costs in exporting back their output.

JEL Classification: O12, O14, R12.

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1. Introduction

In spite of sharp variations across countries, the average degree of industrialization in Europe, as measured by the share of manufacturing value added in GDP, seems to have been increasing moderately since the beginning of the century, a trend which accords with the picture drawn by RODRIK (2016) for the main regions of the world economy.[3]

It has been widely admitted for some time that the variation in industrialization rates across countries and regions can be accounted for by two major causal factors (see, among others, SPILIMBERGO, 1998). The first main determinant is the general trend of transport and communication costs to fall. Until recently, the improvement of transportation has been matched by a similar trend of trade costs, namely *ad valorem* tariffs and other non-tariff barriers to trade. Although some change to an opposite course of action has been taking place recently, there is no reason to believe that a sharp and general reversal of the trend to free trade will occur in the future.

The second major cause of regional asymmetries in industrialization lies in the fast growth in productivity in manufacturing, mainly associated with the automation of increasingly complex tasks. Such gains in industrial efficiency clearly outpace the progress found in non-manufacturing activities.

Most authors have established a causal link between these factors and the geographical variation in industrialization through international trade theory based on the Ricardian *comparative advantage*, which assumes zero factor mobility between countries or regions and complete international mobility of products. For instance, RODRIK (2018) explains the intensity of manufacturing growth in a country by the change in relative unit production costs of manufacturing and non-manufacturing activities, using the world mean evolution of relative costs as a benchmark.

Other *comparative advantage* based approaches use the Hecskher-Ohlin framework, which is founded on differences in relative factor abundance across countries. According to this view, the fall in trade costs gives birth to comparative advantages that were previously hidden. Labor intensive manufacturing operations are moved to low wage countries, or, by contrast, automated industrial processes return to core, capital abundant countries.

We depart from the *comparative advantage* approach as we deal with the spatial differences in manufacturing development by means of the economic geography model by VON THÜNEN (VON THÜNEN , 1826; WARTENBERG, 1966). The crucial difference between Von Thunen's model and the Ricardian *comparative advantage* lies in two opposite assumptions (SAMUELSON, 1983; VENABLES and LIMÃO, 2002). Although production still requires an immobile factor (namely, land), the other factors such as labor are freely mobile. Indeed, the theory explains the equilibrium location of labor. By contrast, it is presupposed that commodities bear positive transport costs, which are product specific.

The structure of VON THÜNEN's economy is well known and it will recalled here in a very summarized way (see HURIOT, 1988 and FUJITA and THISSE, 2002, chapter 3, for more detailed accounts). Economic space is uniform and it will be assumed here that it is a half-line, where the density of land available for productive use is one everywhere. In the origin of the half line there exists a center of activity, which is labelled as the *Town*, where all commodity

[3] This picture would be much different if the share of manufacturing in overall employment would be used instead.

transactions take place. This economy is isolated from abroad and it shows no precise boundary.

In this space, a set of farmers produce different agricultural goods under perfect competition and carry them to the Town, where they are sold at parametric full prices. Each good is produced under constant returns to scale and the standard approach entails the use of land and mobile factors, such as labor, in fixed proportions.[4]

Each farming activity has specific values for a set of parameters, namely the delivered price, the unit transport cost, which is the same everywhere, and the proportions between the different inputs and the output. Since the economy is competitive, farmers' profits become zero in long run equilibrium. Hence, the producers offer a certain rent (the *bid rent*) for the right to use each parcel of land in order to grow a specific crop. Then, equilibrium can be fully described in the following way. Each area of farmland is allocated to the farmer and the crop that yields the highest bid rent. The market land rent is the upper envelope of the bid rent curves of the different agricultural commodities so that a specific crop is grown in a particular only if its bid rent is coincident with the market rent. Finally, the border of the economy is the location where the market land rent equals the opportunity cost of land, which we assume to be zero for simplicity.

The competitive nature of this economy determines that the market equilibrium is socially optimal, in the sense that it maximizes the aggregate surplus of the value of production over transport costs. It can be easily shown that such a surplus is, by definition equal to the total market land rent in the economy. Furthermore, the equilibrium minimizes the aggregate transport cost in the economy. Since the aggregate land rent is a strictly decreasing function of total transport cost, the maximization of the former in each location leads to an overall minimization of the latter.

It is possible to write VON THÜNEN's setting as a general equilibrium model where not only the land rent but also the prices of the farming commodities are endogenously determined. For that purpose, SAMUELSON (1983) and NERLOVE and SADKA (1991) introduce a manufactured good which is produced in the Town and specify the tastes of consumers who might be are either farmers or landowners.

Is VON THÜNEN's economic geography adequate to rationalize the recent changes in the spatial distribution of manufacturing across the European countries? At least since HARRIS (1954), it is generally agreed that the "market" for a given manufacturer is made by a set of centers, whose relative importance (if they are similar in size) depends inversely on how far away they are placed from the industrialist. The assumption of a single and given center of activity seems at odds with reality. However, as FUJITA (2012) noted, the withdrawal of the assumption of a single market center renders the model non-competitive and requires that is set in terms of *monopolistic competition* and increasing returns technology. FUJITA and KRUGMAN (1995) performed this task at the price of a rising complexity analysis and the removal of the equivalence between market equilibrium of locations and the social optimum. As such an equivalence is crucial for our analysis, we will keep ourselves within the Thunian boundaries of a single center of activity.

Another factor behind the choice of the VON THÜNEN' framework, with its emphasis on transport costs of the commodities, is the increasing awareness that it is a useful tool to analyze economic development in backward countries and regions. Gravitational models show that trade flows decrease dramatically with transport costs, the elasticity reaching 2 (EATON and KORTUM, 2002; LIMÃO and VENABLES, 2001). According to STOREYGARD (2016), this

[4] However, Von Thunen's model can be written with producers using land and labor in variable proportions (see among others, BECKMANN (1972), as long as some restrictions on the production function are met.

harmful influence accounts for the fact that in Sub-Saharan African countries where the capital city is also the major seaport, the economic size and growth of secondary cities is explained by the transport costs to the primate city. Natural factors of access to trade, such as a coastal location, appear to be a more important cause of economic density than the availability of fertile land in developing countries (HENDERSON et Al., 2018).

Manufacturing activity seems to be rather concentrated in major urban areas in developing countries, a pattern that is reminiscent of VON THÜNEN's "Isolated State" in the beginning of the nineteenth century. Nowadays, manufacturing activity in Europe is much more decentralized. There are two ways to deal with this apparent contradiction between VON THÜNEN's theory and the reality of contemporary industrial Europe.

The first way, is to integrate both approaches (i.e. "comparative advantage" and "geographical barriers" to trade) within the description of a spatial economy. This path of analysis may consist in generating an "hybrid" theory of location and trade, as EATON and KORTUM (2002) and VENABLES and LIMÃO (2002) did, but we can object that the most basic assumptions of VON THÜNEN and RICARDO-HECKSHER-OHLIN are utterly opposed. An alternative option is to assign the two theories to different geographical scales, as COSAR and FAJGELBAUM (2016) did. While VON THÜNEN's theory would explain the internal geography of a large country, such as India or China, which is spatially organized around a small set of transport hubs (like seaports), "comparative advantage" would account for the nature of trade flows across these "international gates". The latter research line seems to be more solid than the former.

Our approach has a very different nature and it consists in *adapting* VON THÜNEN's economic geography so that it becomes able to rationalize the location of manufacturing units in addition to non-manufacturing (agriculture or services) producers. We will use for that purpose the models with final and intermediate goods that were put by MILLS (1970; 1972, chapter 5) and continued by FUJITA and THISSE (2002, chapter 3).

In Section 2, some stylized facts about geographical patterns of industrialization are described. A formal model of manufacturing location inspired by VON THÜNEN (1826) and MILLS (1970; 1972, chapter 5) is displayed in Section 3, while Section 4 generalizes it to an increasing returns technology. Section 5 summarizes the main results and concludes.

2. Stylized facts about geographical patterns of industrialization

We can outline three main stylized facts concerning the spatial distribution of manufacturing and its evolution in time.

Firstly, manufacturing seems to be much more spatially concentrated in developing countries than in developed countries. In the former, industrial plants agglomerate around main coastal cities, which are also often major seaports, while they are notoriously absent from hinterland cities. This is particularly evident in some Sub-Saharan African countries (see STOREYGARD, 2016), but this can also be evident (although not so clearly) in large developing countries such as China and India (see COSAR and FAJGELBAUM, 2016). By contrast, in Europe, manufacturing activity spills over a wider subset of secondary cities (see HENDERSON et Al., 2018).

Secondly, in what concerns the European Union (see PONTES, 2019), industrialization appears to be concentrated in regions with are neither too close nor too remote to the European core, thus exhibiting an *intermediate* degree of centrality (or accessibility) within the EU. This observation is reinforced by the fact that the relative manufacturing surge appears to be stronger in the states that were admitted more recently to the EU, with most of the elder member states clearly lagging behind.

A third stylized fact (see PONTES, 2019) concerns the location of different industries across European countries. While in the "old" European countries a positive correlation between the industrialization rate and an initial specialization in high-tech sectors is self-evident, such a connection cannot be found across "new" European countries.

3. A formal Von Thunen –Mills model of manufacturing location

3.1. A general view of the model

With a few exceptions, the *Isolated State* gives a reasonable explanation for the location of different agricultural crops relative to an exogenously given market center (the "Town"). Some general equilibrium versions of this model, such as SAMUELSON (1983) and NERLOVE and SADKA (1991), add a manufactured product to the picture but they constrain its location to the activity center. In order to deal with the endogenous determination of manufacturing units within the system of concentric rings, two changes in basic assumptions must be made.

Firstly, manufacturing firms are not bounded to use primary factors (labor and land) to produce. Instead, they process or transform *intermediate goods*, which they purchase to upstream firms. Hence, in order to account for manufacturing location, the analysis cannot be limited to different final consumer goods, but should include also vertical relations between firms, with upstream units producing and selling inputs to downstream manufacturers.

These intermediate inputs may take different forms. They may either be *raw materials* supplied by agriculture or mining, so that the industrial transformation consists in some kind of *refining* or *distilling* (see VON THÜNEN, 1826; WARTENBERG, 1966; LIST, 1841). Or the intermediate might be "labor" itself, supplied by households who play the role of upstream suppliers of this "commodity", using residential land as an input (as in MILLS, 1972, Chapter 5; OGAWA and FUJITA, 1980: FUJITA and OGAWA, 1982).

Secondly, while it is reasonable to expect that farms work under constant returns to scale technology, economies of scale are an essential part of manufacturing processes and should be somehow introduced in the picture. Since we wish to preserve the competitive nature of the spatial economy, we will assume henceforth that there exist increasing returns to scale in manufacturing but *they are external to individual industrial* firms. Hence, in our framework industrial scale economies *stem from the joint use of a fixed input* (a “machine”) by individual industrial firms. Furthermore, we will presuppose that such common facilities will be supplied by the set of landowners and will be paid for by the rise in land rent (or capitalized land value) that follows from the additional investment in fixed capital.

3.2. Assumptions about the spatial economy

In order to rationalize the empirical trends described above, we introduce a VON THÜNEN (1826) spatial economy with two commodities, where, as in MILLS (1970; 1972, chapter 5), product 1 is a final consumer good and product 2 is an intermediate good, which is used as an input to product 1. This setting allows us to deal with the industrial transformation process that characterizes manufacturing. Hence, product 1 is a manufactured good, while the intermediate good can be assigned different meanings depending on the reality to which the model applies.

We presuppose an economic space formed by an half-line $[0,\infty)$, where, in location $r=0$, lies a center of activity, which is labeled as the “Town”. The production of each commodity takes place in locations at distance $r>0$ from the “Town”. The density of land available for productive use in each location is one unit of area. The production of each commodity is made by a large number of competitive firms.

Each good is produced under a constant returns technology within the firm. We assume further for simplicity that the technology also exhibits fixed proportions among factors and output.

For the sake of simplicity (but this assumption could be easily generalized), we also presuppose that commodity 1 is produced only with land and some amount $b>0$ of the intermediate good 2. If we define the units of measure of both commodities adequately, we can set $b=1$. The area used in the production of good 1 per unit of output is expressed by a_1. We further presuppose that commodity 2 is also produced with land only, with a_2 expressing the amount of land required to produce one unit of output.

We assume that the transport activity does not require land, so that the monetary transport cost of product $i=1,2$ is directly proportional to the quantity delivered and to the distance. By definition, one unit of commodity 1 produced in r must be delivered in the center of activity, thereby incurring the transport cost $t_1 r$. By contrast, one unit of commodity 2 produced in location $r'>0$ should be delivered to firm 1 sited in r, which uses it as an input. Hence, the producer of good 2 bears a transport cost given by $t_2|r-r'|$.

In such a spatial economy, it is possible to define a market equilibrium resulting from the decentralized choices of location by firms, which is similar to Von Thünen (1826)'s equilibrium (see MILLS, 1970, 1972, chapter 5; FUJITA and THISSE, 2002, section 3.2.2). Given the assumption of perfect competition in the markets for both products, the profit made by each firm becomes zero in the long run equilibrium. The producer of each commodity $i=1,2$ in location $r>0$ can offer at most the rent $\Psi_i(r), i=1,2; r>0$. Then, the marker land rent in each location will just be the upper envelope of the two bid rent curves.

$$R(r) = \max_i \Psi_i(r), i = 1,2 \tag{1}$$

Then, location $r > 0$, will be allocated to the production of commodity $i = 1,2$ if

$$R(r) = \Psi_i(r), i = 1,2 \tag{2}$$

Furthermore, the perfectly competitive nature of this economy causes that the spatial pattern of production activities resulting from the market equilibrium is coincident with the solution to a planning problem where a central authority sets the allocation of land to the production of goods 1 and 2 so as to minimize the aggregate transport cost of given quantities of commodities 1 and 2 (see MILLS, 1970; 1972, chapter 5).

According to a reason that will be made explicit below, we will define the geographical pattern of the production of each commodity as the solution of the latter type of problem.

3.3. The aggregate transport cost minimizing allocation of land to productive activities under a constant returns technology

We define $x_i(r), i = 1,2$ as the quantity of commodity i that is produced in location r. We further label $\overline{x}$ as the total quantity of either commodity that the overall economy must produce. Finally, we name as $\overline{r}$ the external boundary of the productive area, which is thus given by $(0, \overline{r})$. For locations such that $r > \overline{r}$, the transport costs to the center of activity are so high that only goods that are addressed to local consumption and hence are not carried to the "Town" are produced there.

The workings of the economy is subject to two constraints. The first one, is

$$a_1 x_1(r) + a_2 x_2(r) = 1 \tag{3}$$

Equation (3) is the equality in each location r between the demand for land by producers of goods 1 and 2 (the left hand side of the equality) and the availability of land, which is by assumption equal to one unit of area (the right hand side of the equality).

The second constraint on the allocation of land is that the total the total outputs of products 1 and 2 should be equal.

$$\int_0^{\overline{r}} x_1(r)\, dr = \int_0^{\overline{r}} x_2(r)\, dr = \overline{x} \tag{4}$$

In order to find $\overline{r}$, we integrate both sides of equality (3) to obtain

$$\bar{r} = \bar{x}\left(a_1 + a_2\right) \tag{5}$$

From (5), it follows that the location of the outer boundary of the economy does not depend on the allocation of land in each point of space r to the production of each commodity, but it stems only from the total output of each product $\bar{x}$ and the land requirements to produce either good, a_1 and a_2.

The problem of minimization of the aggregate transport cost of commodities 1 and 2 is

$$\underset{x_1(r),x_2(r)}{\text{Min}}\ C = t_1\int_0^{\bar{r}} r x_1(r)\,dr + t_2\int_0^{\bar{r}}\int_0^{r}\left[x_1(r') - x_2(r')\right]dr'dr \tag{6}$$

subject to constraints (3), (4), (5) and the following one.

$$\int_0^{r}\left[x_1(r') - x_2(r')\right]dr' \geq 0 \quad \text{for } 0 \leq r \leq \bar{r} \tag{7}$$

Constraint (7) follows from the fact that the spatial distribution of productive activities, given by $x_1(r), x_2(r)$, is efficient (i.e. it minimizes (6)) only if every transport of the intermediate good takes place in the direction of the "Town". This is equivalent to impose the condition that, in each location r, there is a flow of commodity 2 that crosses point r inwardly. For this condition to be met, the quantity of good 1 that is produced in region $\left(0, r\right]$ should exceed the quantity of good 2 that is generated in this region, a condition that is expressed by (7). The integral in the left hand side of (7) stands for the flow of units of commodity 2 that crosses location r in the direction to the center of activity.

The objective function C, the aggregate transport cost, is the sum of two parcels. The first one is

$$t_1\int_0^{\bar{r}} r x_1(r)\,dr \tag{8}$$

Or the aggregate transport cost of product 1, which is produced in area $\left(0, \bar{r}\right]$ and then shipped towards the "Town" in $r = 0$.

The second parcel is

$$t_2\int_0^{\bar{r}}\int_0^{r}\left[x_1(r') - x_2(r')\right]dr'dr \tag{9}$$

or the aggregate transport cost of the intermediate good 2. As we have realized in (7), the expression $\int_0^r \left[x_1(r') - x_2(r') \right] dr'$ stands for the flow of commodity 2 units that is shipped through location r towards the center of activity. If we multiply such a flow by $t_2\, dr$, we obtain its transport cost over an arbitrarily small distance. If we further integrate such a shipping cost over the whole productive area, as given by the interval $\left[0, \overline{r}\right]$, we obtain the aggregate transport cost of product 2.

The problem of minimization of (6) in relation to $x_1(r), x_2(r)$, subject to constraints (3), (4), (5) and (7), can be solved through mathematical programming methods (such as optimal control theory), as MILLS (1970) did.

But, following MILLS (1972, chapter 5), it can be easily understood that in this framework there exist only **two** efficient allocations of land to productive activities, which we describe in sequence.

Firstly, there is a "segregated" pattern, where the production of the final consumer good 1 is concentrated around the center of activity, in the interval $\left(0, r^*\right]$, so that its spatial distribution is given by

$$x_1(r) = \begin{cases} \dfrac{1}{a_1} & \text{for} \quad 0 < r \le r^* \\ 0 & \text{for} \quad r^* < r \le \overline{r} \end{cases} \tag{10}$$

The production of commodity 2 takes place in the outer region given by the interval $\left(r^*, \overline{r}\right]$, so that we have

$$x_2(r) = \begin{cases} 0 & \text{for} \quad 0 < r \le r^* \\ \dfrac{1}{a_2} & \text{for} \quad r^* < r \le \overline{r} \end{cases} \tag{11}$$

The value of r^*, the location of the border between the areas producing goods 1 and 2, can be found by substituting allocations (10) and (11) for $0 < r \le r^*$ into condition (3) so as to obtain

$$r^* = a_1 \overline{x} \tag{12}$$

Secondly, there may arise an "integrated" arrangement, where only product 1 experiments transportation and product 2 is locally supplied to the firma that produce good 1. Since, exactly one unit of commodity 2 is required as an input to the manufacturing of one unit of good 1, equal amounts of commodities 1 and 2 should be produced in each location of the productive area, or

$$x_1(r) = x_2(r) \quad \text{for} \;\; 0 < r \le \overline{r} \tag{13}$$

If we substitute (13) in (3) and solve, we obtain the output of each commodity in each and every point of the productive area.

$$x_1(r) = x_2(r) = \frac{1}{a_1 + a_2} \tag{14}$$

Figure 1 plots the two different types of land allocation to the productive activity.

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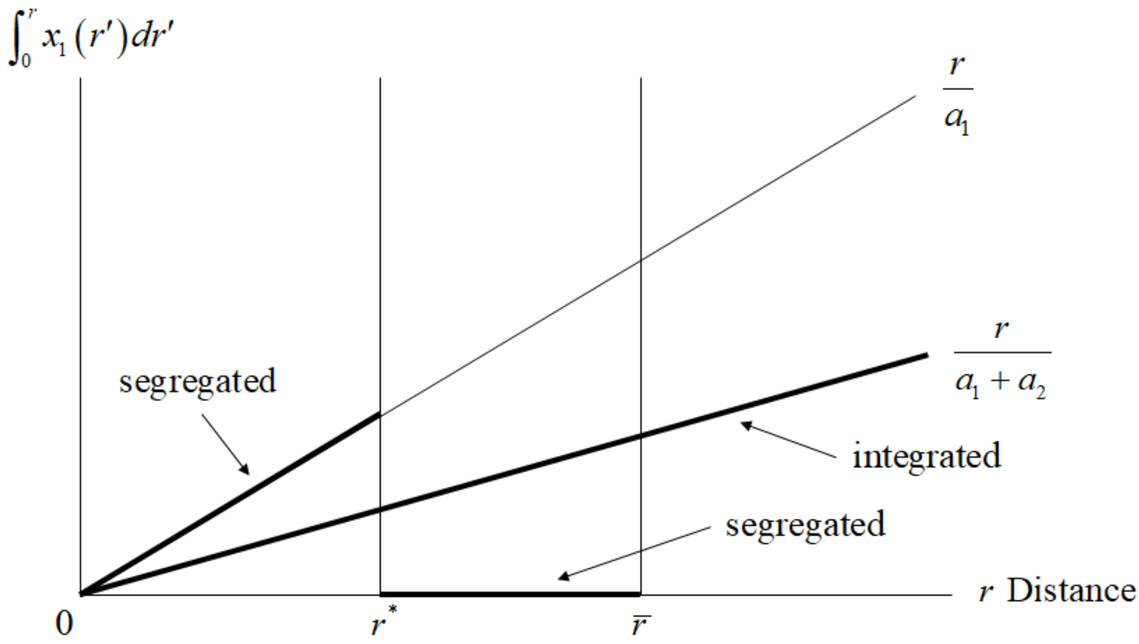

Figure 1: Segregated and integrated patterns of production

Therefore, we can find the socially optimal arrangement of production by computing and comparing the aggregate transport costs of the “segregated” and “integrated” configurations. In what follows, we will perform these calculations.

Finding the aggregate transport cost of the “segregated” pattern

From (6), the aggregate transport cost of commodity 1 under the “segregated” configuration is

$$t_1 \int_0^{\bar{r}} r\, x_1(r)\, dr = \\ = t_1 \left[\int_0^{r^*} r\, x_1(r)\, dr + \int_{r^*}^{\bar{r}} r\, x_1(r)\, dr \right] \tag{15}$$

By using (10), (15) simplifies to

$$t_1 \int_0^{r^*} \frac{r}{a_1}\, dr = = \frac{t_1 \left(r^*\right)^2}{2a_1} \tag{16}$$

By substituting r^* from (12), the aggregate transport cost of product 1 under the "segregated" productive configuration, C_1^S, becomes

$$C_1^S = \frac{t_1 \bar{x}^2 a_1}{2} \tag{17}$$

Turning now to compute the aggregate transport cost of commodity 2 under the "segregated" pattern, it appears to be from (6)

$$\begin{aligned} &t_2 \int_0^{\bar{r}} \int_0^{r} \left[x_1(r') - x_2(r')\right] dr'dr = \\ &= t_2 \left\{ \int_0^{r^*} \int_0^{r} \left[x_1(r') - x_2(r')\right] dr'dr + \int_{r^*}^{\bar{r}} \int_0^{r} \left[x_1(r') - x_2(r')\right] dr'dr \right\} \end{aligned} \tag{18}$$

By using (10) and (11) for $0 < r \le r^*$ and the value of r^* in (12), the double sub-integral $\int_0^{r^*} \int_0^{r} \left[x_1(r') - x_2(r')\right] dr'dr$ in (18) can be solved to yield

$$\frac{\bar{x}^2 a_1}{2} \tag{19}$$

In addition, the double sub-integral $\int_{r^*}^{\bar{r}} \int_0^{r} \left[x_1(r') - x_2(r')\right] dr'dr$ in (18) can also be solved by using (10) and (11) for $r^* < r \le \bar{r}$ and the values r^* and $\bar{r}$ in (12) and (5), respectively, to yield

$$\frac{a_2 \bar{x}^2}{2} \tag{20}$$

We add expressions (19) and (20), then multiply the product by t_2 in order to obtain the aggregate transport cost of commodity 2, C_2^S, under the “segregated” productive arrangement.

$$C_2^S = \frac{t_2 \bar{x}^2 \left(a_1 + a_2\right)}{2} \tag{21}$$

By adding (17) and (21), we obtain the aggregate transport cost under the “segregated” pattern of productive activity.

$$C^S = C_1^S + C_2^S = \frac{\bar{x}^2}{2}\left[a_1 t_1 + t_2\left(a_1 + a_2\right)\right] \tag{22}$$

Finding the aggregate transport cost under the “integrated” productive configuration

Under the “integrated” configuration, only product 1 experiments transportation. Hence, the aggregate transport cost under this land allocation can simply be written as

$$C^I = C_1^I = t_1 \int_0^{\bar{r}} x_1\left(r\right) dr \tag{23}$$

By substituting $x_1\left(r\right)$ from (13) and $\bar{r}$ from (5), the aggregate transport cost under the “integrated” configuration becomes

$$C^I = \frac{t_1 \bar{x}^2 \left(a_1 + a_2\right)}{2} \tag{24}$$

3.4. The determination of the socially optimal spatial allocation of land

By comparing the aggregate transport costs, C^S and C^I, we can determine the geographical pattern that is socially optimal. Since the economy is perfectly competitive, this central planning solution can be sustained in market equilibrium where decentralized 1 and 2 producers offer rents to the landowners, as we noticed above.

Let us assume from the start that a "segregated" pattern prevails. Then, the economy will switch to an "integrated" pattern provided that this condition is satisfied.

$$C^I \leq C^S \tag{25}$$

Substituting (22) and (24) in the inequality, we obtain the following condition

$$\frac{t_1 - t_2}{t_2} < \frac{a_1}{a_2} \tag{26}$$

We presuppose that in general $t_1 > t_2$. Such an assumption can be rationalized by the fact that the unit value of the output of manufacturing is higher than its input. If there is a risk of loss during the shipment, then the "insurance premium" associated with the transport of good 1 is higher than the risk premium following from moving commodity 2.[5] Henceforth, we will regard $\frac{t_1 - t_2}{t_2}$ as a parameter which will be labeled as t^*.

We will focus instead on the right hand side of inequality (26). Let $x_i \equiv \frac{1}{a_i}, i = 1, 2$ be the physical output (in units of weight) of commodity $i = 1, 2$ that can be produced by using one unit of land. Then, we can rewrite inequality (26) as

$$t^* < \frac{a_1}{a_2} = \frac{x_2}{x_1} = \delta \tag{27}$$

The variable $\delta \equiv \frac{x_2}{x_1}$ can be given two different meanings depending on how the intermediate good is regarded within the model. Two possibilities arise.

1. The intermediate good 1 is viewed as an agricultural raw material. Then, manufacturing is viewed in its essence as a "weight-losing" process, where a heavy input (for instance, a "cereal") is "refined" (i.e. "milled" or "distilled") into a much lighter output ("flour" or "alcohol"), which can thus be more easily shipped over long

[5] Von Thunen (1826) makes a similar assumption for an economy with two consumer goods. The product raised around the Town (i.e. "vegetables") is supposed to be more "perishable" during transportation than the crop raised in the outer ring (i.e. "cereals").

distances. Variable δ stands for a “refining rate”, which expresses the relative weight loss of the input during industrial transformation. This is the original view on manufacturing by VON THUNEN (1826) and LIST (1841).

2. Contemporary authors, such as MILLS (1972, chapter 5), OGAWA and FUJITA (1980) and FUJITA and OGAWA (1982), interpret the intermediate good as “labor”. Therefore, commodity 2 producers are viewed as “households” who use “residential land” for that purpose. Transport costs of good 2 are just commuting costs. Under this perspective, variable δ appears as the **labor intensity of the productive process.**

The model that was thus far described helps us to explain two main trends of industrialization in Europe, that were summarized in section 2.

The first trend is that industrialization is relatively stronger within the EU in areas that are placed neither too close nor too far away from the European core but stay rather at an **intermediate** distance from Brussels. This model contains a similar spatial division in the case of a “segregated” pattern of production (see Figure 1), with the partition of market space in three contiguous intervals. Apart from the “Town” in $r = 0$, the market space is $\left(0, r^*\right] \cup \left[r^*, \bar{r}\right] \cup \left[\bar{r}, \infty\right]$. It is clear that the transition from “segregated” pattern to an “integrated” one implies a decrease of production of commodity 1 (manufacturing) around the activity center, in $\left(0, \bar{r}\right]$, in relation to overall production, and its relative increase in the intermediate area $\left[r^*, \bar{r}\right]$. The outer region $\left[\bar{r}, \infty\right)$ continues to not having any kind of industrial (or otherwise tradable) production.

The second trend that inequality (27) allows to understand better is that core European countries, which correspond roughly to “old” countries within the EU, tend to experiment a loss of manufacturing activity in proportion to their specialization in labor intensive industries. By contrast, this connection seems to be missing in more peripheral countries, which were newly admitted in the EU. Such countries seem to have benefited from a shift of labor intensive industries, which were formerly located in the EU core.

4. A simple extension to an economy under (external) increasing returns

The spatial economy modeled above, which is inspired in VON THÜNEN (1826) and MILLS (1970; 1972, chapter 5), is perfectly competitive, so that the socially optimal land allocation can be sustained as a decentralized market equilibrium resulting from land rent bidding by producers. Hence, in our framework, the total market land rent always equals the social surplus, i.e., the difference between the value of aggregate production and total transport costs.

However, our model suffers from a rather serious limitation as a theory of manufacturing location since it assumes that production takes place under constant returns to scale (indeed, under fixed factor proportions), while in industrial activity economies of scale associated with fixed inputs play a crucial role. Consequently, in this section, we will introduce increasing returns to scale and fixed costs, while keeping the assumption of perfect competition. Such an assumption is essential in order to preserve the equivalence between market equilibrium and social optimum, which is a cornerstone of our analysis. For increasing returns and perfect competition to be compatible, we will introduce in our picture economies of scale and fixed costs that are **external** to individual manufacturing firms.

This will be done as follows. In the case that the "segregated" allocation prevails from the start, we assess the feasibility of the transition to an "integrated" pattern. We assume now that production of commodity 1 incurs a fixed cost F related with the acquisition with an "equipment" or "machine", which depreciates completely during the time period of analysis. We further assume that this fixed cost is **external** to individual industrialists. Such a "machine" is provided collectively by the landowners and it is shared and used jointly by all manufacturing units.

The use of the "common machine" by a producer of good 1 is assumed to be free of charge except for the fact that the manufacturer must bear a transport cost between the fixed equipment and its own location. We deal with this transport cost in an "implicit" or approximate way. We presuppose that while the "segregated" pattern requires a single "machine", which is sited in the "Town", the "integrated" configuration requires the setting of a second fixed facility outside the center of activity and closer to the industrialists as they become dispersed over much wider distances.

Given the equivalence between market equilibrium and social optimum, if the economy switches from the "segregated" to "integrated" pattern, the difference between the aggregate transport costs under the two configurations $C^S - C^I$ equals necessarily the variation in total market land rent ΔR. Hence, landowners will install a second "machine" thereby making the transition possible only if

$$\Delta R = C^S - C^I \geq F \tag{28}$$

If we substitute (22) and (24) in (28) and solve it, the following condition for the arise of an "integrated" pattern is obtained.

$$\frac{t_1 - t_2}{t_2} \leq \frac{a_1}{a_2}\left(1 - \frac{2F}{\overline{x}^2}\right) \tag{29}$$

As before, let $t^* \equiv \frac{t_1 - t_2}{t_2} > 0$ be a transport parameter and $\delta \equiv \frac{a_1}{a_2} = \frac{x_2}{x_1}$ be a variable expressing the "refining rate" of a raw material or just the "labor intensity" of manufacturing. Then, we can write (29) as

$$\delta \geq \frac{t^*}{1 - 2\left(\frac{F}{\overline{x}^2}\right)} \tag{30}$$

Condition (30) generalizes (27) by introducing the relative importance of scale economies $\frac{F}{\overline{x}^2}$ as an explaining variable. In order that manufacturing decentralizes and integrates with primary production or workers' residences, variable δ should be high enough not only in absolute terms but also in relation to importance of economies of scale.

Condition (30) sheds further light on some empirical trends of industrial location. As we noticed in section 2, the higher industrial agglomeration level in developing countries relative to developed states can be reasonably explained by the increased burden represented by fixed costs F in relation to a low aggregate output $\overline{x}$.

5. Concluding remarks

We used a location model due to VON THÜNEN (1826) and MILLS (1970; 1972, chapter 5) to find out the patterns that the spatial distribution of manufacturing might possibly assume. In a homogeneous space which is organized around an activity center (a “Town”), a set of competitive firms produce two complementary commodities. While product 1 is a final consumer good, product 2 is an intermediate good. Firms in both vertically related stages use land and downstream producers of commodity 1 use also product 2 as an input. The productive activity takes place under constant returns to scale, the technical proportions among factors and products being assumed to be fixed.

Since the economy is perfectly competitive, there is an equivalence between the spatial pattern of production that arises from the decentralized workings of the land market (the “market equilibrium” set of locations) and the geographical arrangement that solves a central planner’s problem of minimization of aggregate transport cost for given quantities produced of each commodity. Then, a standard welfare property allows us to find out precisely the equilibrium of productive location simply by solving the central planner’s problem.

MILLS (1970; 1972, chapter 5) has shown that there are only two solutions to such a problem that might possibly be efficient: a pattern where upstream production takes place far away from the center of activity, downstream manufacturing being “segregated” in a region around the “Town”; and a configuration where upstream and downstream producers are locally “integrated”, so that the intermediate good is supplied locally without incurring any kind of transportation.

We further introduce increasing returns in this economy since they are an essential part of manufacturing operation, while keeping the competitive framework unchanged. For that purpose, we presuppose that economies of scale are **external to the firm** and derive from a fixed input (a “machine”) which is used jointly by all manufacturers. The transition from “segregated” to spatially “integrated” industrial plants implies the setup of an additional “machine” by the landowners, who find such an investment profitable only if the resulting increase in total land rent covers the fixed cost.

This model can be interpreted in two different ways. Either the intermediate good is viewed as a raw material that is produced by farmers and successively “refined” by a manufacturer who uses a “mill” or “distillery” for that purpose, or it can stand for “labor” supplied by households with residential land. The economic results are the same in both cases.

The model shows that the decentralization of manufacturing takes place more likely in industries with high labor intensity or high “refining rates” of raw materials and relatively small fixed costs requirements. The factories that relocate will likely stay in areas at an **intermediate** distance from the center of activity rather than in remote territories as they would then face prohibitive transport costs in exporting back their output.

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