Structural Change and Economic Dynamics 59 (2021) 567–574

Contents lists available at ScienceDirect

Structural Change and Economic Dynamics

journal homepage: www.elsevier.com/locate/strueco

A geographical theory of (De)industrialization

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ARTICLE INFO

Article history:
Received 8 March 2021
Revised 9 July 2021
Accepted 25 October 2021
Available online 28 October 2021

JEL Classification:
B20
O12
O14
R12

Keywords:
Deindustrialization
Industrialization of Agrarian economies
Von Thünen
Friedrich list

ABSTRACT

In the model of agricultural land use and rent of Von Thunen (1826), manufacturing decentralization is viewed as the refining (or "distilling") of an agricultural commodity near the cultivation site, which substitutes for its transport to an industrial mill located in the Town. As Friedrich List (1841) added, this substitution is economically feasible only if the savings in transport cost following from in site refining cover the increase in fixed costs associated with a second industrial plant. We update this approach aiming to rationalize some stylized trends of manufacture relocation nowadays, which are jointly labeled as "deindustrialization".

1. Introduction

With 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 that accords with the picture drawn by Rodrik (2016) for the main regions of the world economy.[1]

It has been widely admitted for some time that the variation in industrialization rates across countries and regions can be accounted for – although not exclusively - 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.[2] Such gains in industrial efficiency clearly outpace the progress found in non-manufacturing activities.

Some have established a causal link between these factors and the geographical variation in industrialization through the 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 (2016) 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 approaches based on the *comparative advantage* concept use instead 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.

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

[2] Other important factors for regional asymmetries are increasing returns, preferences, agglomeration economies, or first nature advantages (Krugman, 1993).

https://doi.org/10.1016/j.strueco.2021.10.010

We depart from the *comparative advantage* approach, given that we deal with the spatial differences in manufacturing development using the economic geography model of Von Thünen (1826). The crucial difference between the latter 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), 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.

Is Von Thünen (1826)'s's economic geography adequate to rationalize the recent changes in the spatial distribution of manufacturing across the European countries? Several issues should be handled. 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, which is fundamental in the *Thünian* framework, 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 an 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 *Thünian* boundaries of a single center of activity.

Another factor behind the choice of the Von Thünen (1826)'s 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, so that the elasticity might reach 2, i.e. a ten percentage point increase in transport costs typically reduces trade volumes by about 20 percent (Eaton and Kortum, 2002; Limão and Venables, 2001). According to Storeygard (2016), this 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 (1826)'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 (1826)'s theory and the reality of contemporary industrial Europe.

The first kind of approach consists in integrating 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 a "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 we find in Cosar and Fajgelbaum (2016). While Von Thünen (1826)'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), the "comparative advantage" framework could 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 builds on the analysis on industrial relocation made by Von Thünen (1826) in the chapter on "Distilling". There he deals with the productive location of a cereal, such as wheat. In an initial stage, this crop is raised and then carried as a raw material to the Town. Here it is refined (or "distilled") by means of a fixed equipment into alcohol as a final output. The author assumes that in the beginning there are "restrictive regulations" that constrain the distilling activity to be concentrated in the Town. Under this constraint, the cultivation of wheat must take place not too far away from the activity center, since wheat is heavy and difficult to transport.

However, if it happens that, in a second stage, the administrative constraints on the distilling location are removed, then a decentralized refining machine can be installed aside the wheat field. Since alcohol has a much lower weight per unit of value than the raw cereal, the raising of this kind of crop becomes profitable in areas that are much more distant from the Town than before.

Hence, Von Thünen (1826)'s model includes both a theory of industrialization of peripheral areas, which were formerly purely agrarian, and the "deindustrialization" of the Town and its suburbs, which lose a considerable share of its initial manufacturing output.

However, the insight by the great German economist does not contain yet an *economic* model of manufacturing decentralization, since it completely depends on a switch of political regulations on manufacturing activities. By reading carefully Mills (1970, 1972, chapter 5), who attempted to formalize Von Thünen (1826)'s insight, we can understand why it is so. Concerning this issue, an important assumption is that both primary production and manufacturing take place under constant returns to scale and a fixed proportions technology. In what concerns *primary* factors of production, the proportions between land and other factors, such as labor, are fixed. This assumption allows us to reduce all the costs incurred by the producers simply into transport costs. Hence, if manufacturing is weight losing, the relocation of industrial plants to outer areas is always profitable, and we need to resort to exogenous factors, such as "political restrictions", in order explain its timing.[3]

In this context, List (1841) offered a crucial insight by stressing that manufacturing should be regarded as an *increasing returns* activity, which contrasts with the mostly constant returns to scale nature of agriculture. To set up a second decentralized industrial plant, an additional fixed cost must be borne. Such a fixed outlay should be covered by the decrease in aggregate transport costs caused by the industrial investment.

With this change, the economy still operates under perfect competition because farmers use jointly the refining equipment, so that economies of scale are *external* to each individual producer. List (1841) assumes that the second refining machine is provided collectively by the landowners, who use for that purpose the proceeds of the rise in total land rent that derives from the industrial investment. In a competitive economy where all factors of production are in fixed proportions with land, the variation in total land rent is coincident with the decrease in aggregate transport costs. Hence, when the installation of a decentralized refining machine is profitable from the landowners' private viewpoint, it is also socially optimal as it minimizes total production and transport costs.

Our analysis confirms the main result of the "new economic geography" approach by Krugman (see Krugman, 1991; Fujita et al.,

[3] Exogenous factors where lengthily discussed by Krugman (1993) under the label of first nature advantages. Besides political factors, this can include natural resources, natural infrastructures (such as as navigable rivers and access to the sea), arable land, physical landscape (e.g. Absence of natural obstacles as mountains, temperature, rainfall, and so on.

1999; Gaspar, 2021) that the decentralization of any increasing returns activity such as manufacturing is related with high transport costs, but it adds a crucial insight. In our framework, industrial decentralization follows both from high overall transport costs and from a change in their internal structure, where transport costs of manufacturing output become significantly lower in relation to the costs of moving primary goods (agricultural products or labor). Concerning this point, Helpman (1998) developed an economic geography model that involves two complementary goods, namely housing services and a differentiated manufactured product, where agglomeration might emerge for high transport costs of final goods. However, this model is cast under stricter assumptions than ours since it features a two-region economy and the upstream, land-using commodity is assumed to be non-tradable.

A caveat should be done about how suitable it is to apply Von Thünen (1826)'s theory to modern times, since it was developed in the context of a very different economy and society. We believe that, while a part of an old economist's work is undoubtedly context-specific, some abstract concepts relating to the operation of a general market economy may be transposed over time. This explains why theoretical concepts put forward by Von Thünen's contemporary economists, such as Ricardo (1821) or Augustin Cournot (1838), still belong the core of modern economic theory. Furthermore, this paper builds not only on Von Thünen's work but rather on a whole strand of nineteenth century German economists, starting with the author of *The Isolated State* but including also List (1841) and Launhardt (1885), who all emphasized the increase in the transportability of output in relation to the input as a crucial element of every industrialization process.

In what follows, in section 2, we summarize some stylized facts of contemporary trends of manufacturing relocation, which the model in this paper purports to explain fully. In section 3, the formal model is presented in detail. Section 4 discusses the results and indicates likely paths for additional examination.

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 may also appear (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 seems to be concentrated in regions, which 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 a 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 remining behind the former ones.

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 model of industrial decentralization

3.1. Concentration of manufacturing in a Town (period 0)

The economy is made up by a half line $[0, \infty)$. There is a Town in point $r = 0$. The density of land available for productive activity in each $r > 0$ is one unit.

In period 0, a large group of competitive farmers produce a fixed amount of $\bar{x}$ units of an agricultural good, which is labelled as "commodity 1″, using a fixed proportions technology. For simplicity, we will assume that one unit of output is produced with one unit of land as the single input. This is a closed economy with a fixed number $\bar{x}$ of primary producers whose border lies at a distance $\bar{r} = \bar{x}$ from the Town.

The producers deliver the agricultural good in the Town, which performs two distinct economic functions. The agricultural raw material is transformed into a final consumer good. For that purpose, the farmers use jointly a "machine", which implies only a fixed cost F, without any operating costs, and it is assumed to depreciate fully during the current period. We further assume that the landowners provide the "machine" collectively. The landowners use the proceeds of total land rent for that purpose.

The Town also works as an export terminal of the manufactured good. Farmers sell the processed goods at the competitive price p and these products are then exported.

While carrying the consumer good to the Town, the farmers bear a unit transport cost t_1.

Following Von Thünen (1826), a market equilibrium arises if land is allocated to the producer that bids the highest rent in each location. This means that the productive area is given by $(0, \bar{r})$, the outer limit being set as $\bar{r} = \bar{x}$. The land rent in each location equals the bid rent and is,

$$R_0(r) = p - t_1 r \tag{1}$$

The competitive price of the product when it is delivered by farmers in the Town is endogenously determined by the condition that the market land rent at the outer limit of the productive area is zero.

$$R_0(\bar{r}) = 0$$

Taking in account expression (1), we notice clearly that the competitive price of the agricultural commodity at the Town is determined by the marginal transport cost, i.e. by the transport cost borne by the farmer placed at the outer limit of the farming area.

$$p = t_1 \bar{r} = t_1 \bar{x} \tag{2}$$

Under these conditions, total market land rent is

$$\begin{aligned} TR_0 &= \textstyle\int_0^{\bar{x}} (p - t_1 r) dr = \\ &= p\bar{x} - \textstyle\int_0^{\bar{x}} t_1 r dr \\ &= p\bar{x} - \tfrac{t_1 \bar{x}^2}{2} \end{aligned} \tag{3}$$

While the first term in (3) stands for total revenues of farming activity, the second term represents its total transport costs in period 0, which are,

$$C^0 = \int_0^{\bar{x}} t_1 r dr = \frac{t_1 \bar{x}^2}{2} \tag{4}$$

If we substitute p from (2) into (3), the total land rent becomes

$$TR_0 = \frac{t_1 \bar{x}^2}{2} \tag{5}$$

Since the industrial plant sited in the Town is funded by the set of landowners, this spatial economy is feasible only if total land

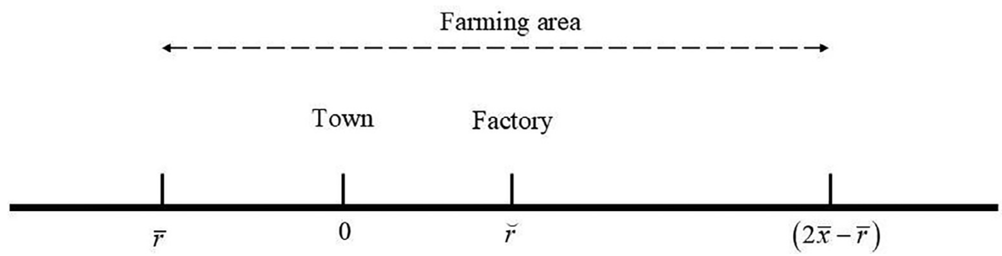

Fig. 1. Optimal location of a single factory.

rent covers the "machine" fixed cost. From (5), we have the condition,

$$TR_0 = \frac{t_1\bar{x}^2}{2} > F\text{or} \quad t_1 > 2\left(\frac{F}{\bar{x}^2}\right) \tag{6}$$

Condition (6) means that transport costs of the farming product should be sufficiently high and the economy must attain a minimum size in order to break even.

Up to now we have stated without proof that if a single factory breaks even, it will locate optimally at the Town in point $r = 0$.

However, we can further assess the optimal locations of both the factory and the farmers over a **line** $(-\infty, \infty)$, with an export terminal of the finished product sited at the origin. Let t_2 be the unit transport cost of the final consumer good, where we assume that $t_1 > t_2 > 0$. We define $\delta \equiv \frac{t_1 - t_2}{t_1}$ as the "refining rate" of the industrial process which measures the gain in transportability of the manufactured output relative to the input.

Then, we can prove the following proposition.

Proposition 1. . Let us assume that the Von Thünen (1826)'s economy is displayed over a line, i.e., the set $(-\infty, \infty)$. If an industrial machine is set up in such an economy and the refining rate δ exceeds $\frac{1}{2}$, then the equilibrium pattern of productive locations is unique and consists in the location of the factory at the Town and the placement of farmers along a connected interval centered around the origin of the line $[-\bar{x}, \bar{x}]$.

Proof. Given the welfare properties of the model, we will assess the pattern of equilibrium locations by finding out the spatial configuration that minimizes aggregate transport costs.

Since they are self-evident, we will assume without proof the following assertions.

1. In an aggregate transport cost-minimizing arrangement, the farming area should be connected, without "holes" (vacant land).

2. In an aggregate transport cost-minimizing pattern, the locations of both the Town and the factory should be interior points to the farming area.

We plot the Von Thünen (1826)'s economy in Fig. 1. Each place outside the Town is labeled by a distance to the origin and by a sign. We name as $\breve{r}$ the industrial unit place and by $\bar{r}$ the left-hand side boundary of the farming area. We presuppose without loss of generality that the factory is placed on the right-hand side of the Town, so that $\breve{r} > 0$. Since in Fig. 1 there is no ambiguity, each point will be labeled by a positive number corresponding to a distance to the origin.

We now write the aggregate transport cost function in relation to two arguments, $\breve{r}$ and $\bar{r}$, which includes both the total transport cost of the raw a material at a rate t_1, $TC_1(\bar{r}, \breve{r})$, and the total transport cost of the finished product at the rate t_2,$TC_2(\breve{r})$. Thus, we have

$$TC\left(\bar{r}, \breve{r}\right) = TC_1\left(\bar{r}, \breve{r}\right) + TC_2\left(\breve{r}\right) \tag{7}$$

Thus meaning

$$TC_1 = t_1\left\{\int_0^{\bar{r}} (\bar{r} - r)dr + \int_0^{\breve{r}} \left(\breve{r} - r\right)dr + \int_{\breve{r}}^{2\bar{x}-\bar{r}} [(2\bar{x} - \bar{r}) - r]\,dr\right\}$$
$$TC_2 = t_2\left(2\bar{x}\breve{r}\right) \tag{8}$$

Hence, the aggregate transport cost is,

$$TC\left(\bar{r}, \breve{r}\right) = t_1\left\{\int_0^{\bar{r}} (\bar{r} - r)dr + \int_0^{\breve{r}} \left(\breve{r} - r\right)dr + \int_{\breve{r}}^{2\bar{x}-\bar{r}} [(2\bar{x} - \bar{r}) - r]dr\right\} + t_2\left(2\bar{x}\breve{r}\right) \tag{9}$$

The optimal spatial pattern of the productive activity minimizes function (9) in relation to $\bar{r}$ and $\breve{r}$, subject to the constraints

$$0 \leq \bar{r} \leq 2\bar{x}$$
$$0 \leq \breve{r} \leq 2\bar{x} - \bar{r} \tag{10}$$

The first partial derivatives of (9) are,

$$\frac{\partial TC}{\partial \bar{r}} = \frac{\partial TC_1}{\partial \bar{r}} = t_1\left[\breve{r} + 2(\bar{r} - \bar{x})\right]$$
$$\frac{\partial TC}{\partial \breve{r}} = t_1\left[\bar{r} + 2\left(\breve{r} - \bar{x}\right)\right] + 2t_2\bar{x} \tag{11}$$

The Hessian matrix of function (9) is,

$$\begin{bmatrix} \frac{\partial^2 TC}{\partial \bar{r}^2} & \frac{\partial^2 TC}{\partial \bar{r}\partial \breve{r}} \\ \frac{\partial^2 TC}{\partial \breve{r}\partial \bar{r}} & \frac{\partial^2 TC}{\partial \breve{r}^2} \end{bmatrix} = \begin{bmatrix} 2t_1 & t_1 \\ t_1 & 2t_1 \end{bmatrix} \tag{12}$$

which is clearly positive definite. Hence, function (9)is a strictly convex function. Consequently, the necessary conditions of a local minimum subject to constraints (10), the so-called Kuhn-Tucker conditions, are also necessary and sufficient conditions of a unique minimum.

We check now whether the point whose coordinates are $\bar{r} = \bar{x}$and $\breve{r} = 0$ meets the first order conditions. Since $\bar{r} = \bar{x}$ is an interior point, the Kuhn-Tucker condition is just $\frac{\partial TC}{\partial \bar{r}}(\bar{r}, \breve{r}) = 0$. By contrast,$\breve{r} = 0$ is a boundary point, so that the first order condition is $\frac{\partial TC}{\partial \breve{r}}(\bar{r}, \breve{r}) \leq 0$.

It is clear that the conditions,

$$\frac{\partial TC}{\partial \bar{r}} = t_1\left[\breve{r} + 2(\bar{r} - \bar{x})\right] = 0$$
$$\frac{\partial TC}{\partial \breve{r}} = t_1\left[\bar{r} + 2\left(\breve{r} - \bar{x}\right)\right] + 2t_2\bar{x} \leq 0$$

are met by the point $(\bar{r}, \breve{r}) = (\bar{x}, 0)$ if and only if,

$$\bar{x}(2t_2 - t_1) \leq 0 \Leftrightarrow \delta \geq \frac{1}{2} \tag{13}$$

where $\delta \equiv \frac{t_1 - t_2}{t_1}$ is the degree of weight loss during transformation, i.e. the relatively gain in product lightness and ease to be moved. *Q.E.D.*

The proposition ensures that if a machine is provided and the industrial process is enough weight losing, then the equilibrium locations of both farmers and the factory will be symmetrical in relation to the Town.

This result supports our assumption of a space made up by a half-line, where both the Town and a single factory stand at the origin. This assumption will be made in the remaining part of this paper.

3.2. The spread of manufacturing outside the Town (period 1)

We assume that the fixed cost F related with the setting up of a single factory in time 0 is in fact a sunk cost. Hence, it is presupposed that the industrial plant that was installed in the Town in the beginning remains operating there when the economy passes to the following stage.

According to Von Thünen (1826), List (1841) and Mills (1970; 1972, chapter 5), we now introduce the possibility of an industrial transformation of the agricultural output at a distance from the Town. As before, one unit of the farming good 1 is transformed into a manufactured good (named now as "product 2″), by using a piece of fixed equipment, which is assumed to occupy an infinitesimally small amount of land.

We continue to assume that the manufacturing process implies only the fixed cost F of the machine and it consists in a "refining" of a raw material, which loses a significant amount of weight during its transformation. Consequently, the unit transport costs of the two products satisfy the inequality $t_1 > t_2 > 0$ and the "machine" should be viewed as a "milling" or "distilling" plant.

We model this economy as a decentralized Von Thünen (1826)' system, where each competitive farmer chooses between two alternative activities namely,

- "Activity 1″, that consists in producing one unit of an agricultural raw material with one unit of land and delivering it directly in the Town at $r = 0$, where it is refined and exported at the competitive price p.
- "Activity 2″, that consists in raising one unit of an agricultural raw material, delivering it at the "machine" location at $\hat{r} > 0$ to be refined and finally carried into the Town.

Given the competitive nature of this spatial economy, there is an equivalence between the land allocation following from the decentralized decisions of farmers and landowners and the spatial arrangement that maximizes total land rent. It is well known that in a Von Thünen (1826) economy, each productive lot is assigned to the activity that can bid the highest rent, so that the market land rent curve is just the upper envelope of the two bid rent curves by activities 1 and 2.

Since rent is maximized in each lot, the overall geographical pattern also maximizes total land rent, which is the difference between total revenues earned and total costs borne by the producers. From the assumption that the total output of the commodity sold in the market center $\bar{x}$ is exogenously given, it follows that the competitive spatial pattern of production should minimize total costs. As land is assumed the single primary factor of production, we only need to take in consideration the transport costs. Consequently, we can be sure that the interactions among farmers in the land market determine a spatial configuration that minimizes aggregate transport costs.

The issue of industrialization of a former agrarian economy raises two successive questions. First, will the landowners find profitable to install a second refining machine located in the countryside? Second, if they decide to carry out the industrial investment, where will the manufacturing plant be located? As usual, we will try to answer these questions backwardly, starting with the latter one.

3.2.1. The optimal location of the industrial plant

The landowners will select a location for the refining machine to maximize total land rent, i.e., the difference between aggregate revenue and transport cost.

Aggregate revenue does not change with industrial investment and, according to (2), it remains equal to

$$p\bar{x} = t_1\bar{x}^2 \tag{14}$$

Hence, the optimal location for an industrial plant from the landowners' viewpoint minimizes the aggregate transport cost (see Fig. 2).

Let $\hat{r} \in (0, \bar{r})$ be the refining machine location. Then, the aggregate transport cost under industrialization, in period 1, is

$$C^1 = C_1^1 + C_2^1 \tag{15}$$

where C_1^1andC_2^2 stand for the aggregate transport costs of the raw material 1 and the refined (manufactured) good 2, respectively. The optimal site for the industrial from the viewpoint of landowners maximizes total land rent and this amounts to minimize aggregate transport costs.

Besides points $\bar{r}$and$\hat{r}$ in Fig. 1, we have a third point $\tilde{r}$ which stands for the location of the farmer who is indifferent between activities 1 and 2, i.e. between delivering directly the raw material to the Town or carrying it to the decentralized machine in order to be transformed and finally brought into the Town. Point $\tilde{r}$ solves the equation,

$$t_1\tilde{r} = t_1\left(\hat{r} - \tilde{r}\right) + t_2\hat{r} \tag{16}$$

Hence, producers in $(0, \tilde{r})$ decide to deliver the farming output straight into the Town, whereas farmers in $(\tilde{r}, \hat{r})$ minimize transport costs by carrying it first to the "machine" and then into the Town. Clearly, producers located to the right of $\hat{r}$ reach a minimum transport cost by first refining the agricultural output. The solution of Eq. (16) is,

$$\tilde{r} = \hat{r}\left(\frac{t_1 + t_2}{2t_1}\right) \tag{17}$$

Since by assumption $t_2 < t_1$, then $(\frac{t_1+t_2}{2t_1})$ in expression (17) is smaller than 1 so that $\tilde{r} < \hat{r}$ as it is depicted in Fig. 2.

Bearing in mind Fig. 2, the total transport cost of the raw material 1, C_1^1 is

$$C_1^1 = \int_0^{\tilde{r}} t_1 r dr + \int_{\tilde{r}}^{\hat{r}} t_1\left(\hat{r} - r\right)dr + \int_{\hat{r}}^{\bar{r}} t_1\left(r - \hat{r}\right)dr \tag{18}$$

The total transport cost of product 2, C_2^1, concerns the units of the agricultural commodity that are raised by farmers in the region $(\tilde{r}, \bar{r})$, at the rate of one unit of output per unit of land. These units are first refined in point $\hat{r}$ and then they are dispatched to the Town to be sold there. The total transport cost of the manufactured good 2 is

$$C_2^1 = t_2\hat{r}\int_{\tilde{r}}^{\bar{r}} dr \tag{19}$$

By summing C_1^1 from expression (18) and C_2^1, from (19), we can write the aggregate transport cost as follows.

$$\begin{aligned} C^1 &= C_1^1 + C_2^1 = \\ &= \left[\int_0^{\tilde{r}} t_1 r dr + \int_{\tilde{r}}^{\hat{r}} t_1\left(\hat{r} - r\right)dr + \int_{\hat{r}}^{\bar{r}} t_1\left(r - \hat{r}\right)dr\right] + t_2\hat{r}\int_{\tilde{r}}^{\bar{r}} dr \end{aligned} \tag{20}$$

The aggregate transport cost in (20) is a function of three variables, namely $\tilde{r}, \hat{r}$ and $\bar{r}$ (recall Fig. 2). However, if we perform the substitutions $\bar{r} = \bar{x}$ and $\tilde{r} = \hat{r}(\frac{t_1+t_2}{2t_1})$, from (17), it becomes a function of the location of the second refining unit only, which we can thus name as $C^1(\hat{r})$ and it is given by the expression,

$$C^1\left(\hat{r}\right) = \frac{\bar{x}^2 t_1}{2} - \bar{x}\hat{r}(t_1 - t_2) + \frac{\hat{r}^2}{4t_1}(t_1 - t_2)(3t_1 + t_2)$$

Fig. 2. Spatial economy with two refining machines.

If we introduce the "refining rate" $\delta \equiv \frac{t_1 - t_2}{t_1}$ in $C^1(\hat{r})$, the aggregate transport cost can be written in terms of δandt_1**.**

$$C^1\left(\hat{r}\right) = \frac{t_1}{2}\left[\bar{x}^2 - 2\hat{r}\bar{x}\delta + \frac{\hat{r}^2\delta}{2}(4-\delta)\right] \quad (21)$$

The second derivative of the aggregate transport cost function can be computed to yield,

$$\frac{d^2C^1\left(\hat{r}\right)}{d\hat{r}^2} = \frac{t_1\delta}{2}(4-\delta) \quad (22)$$

Since by assumption $0 < \delta < 1$, $C^1(\hat{r})$ is a strictly convex function whose minimum is defined by the first order condition of a local minimum. By computing the first derivative of $C^1(\hat{r})$ and equating to zero, the aggregate transport cost minimizing location for the decentralized plant is given by,

$$\hat{r}^* = \frac{2\bar{x}}{4-\delta} \quad (23)$$

Three comments are motivated by (23).

- The optimal distance of the second industrial machine from the Town increases with size of the productive area $\bar{r} = \bar{x}$.
- While this distance does not hinge upon the absolute level of transport costs it is critically related with their internal structure δ, so that the manufacturing unit is the more decentralized the higher the relative weight loss that takes place under industrial transformation.
- Since $0 < \delta < 1$, the optimal location of the second factory belongs necessarily to the region $(\frac{\bar{r}}{2}, \frac{2\bar{r}}{3})$. Hence, it has an intermediate level of accessibility in relation to the Town. This stems from the fact that it should be central relative to the whole set of producers of its intermediate input.

3.2.2. Is industrialization economically feasible?

The landowners will collectively provide a "refining factory" to be sited in point $\hat{r}^* = \frac{2\bar{x}}{4-\delta}$ if the ensuing increase in total land rent ΔTR covers the fixed cost of installing a second manufacturing equipment. As we have argued above, ΔTR is just the difference between the aggregate transport costs with *one* and with *two* industrial units.

$$\Delta TR\left(\hat{r}\right) = C^0 - C^1\left(\hat{r}\right) \quad (24)$$

In the expression of ΔTR, while the aggregate transport cost with a single industrial plant is given by (4), this variable with two manufacturing units is expressed by (21).

The increase in total land rent following from the investment in a second industrial plant depends on the precise location of this plant. We can obtain the maximum value of ΔTR by substituting in (24) the optimal point of space where to place the second refining plant, i.e. $\hat{r}^*$ as given by (23). The maximal rise in total land rent is,

$$\max_{\hat{r}} \Delta TR = \frac{\bar{x}^2 t_1 \delta}{4-\delta} \quad (25)$$

Then, it is straightforward to write the condition of economic feasibility of the investment in second refining unit by the set of landowners. The associated maximal rise in total land rent should cover the additional fixed cost, i.e.

$$\max_{\hat{r}} \Delta TR = \frac{\bar{x}^2 t_1 \delta}{4-\delta} > F$$

Or equivalently

$$t_1 > \left(\frac{4-\delta}{\delta}\right)\left(\frac{F}{\bar{x}^2}\right) \quad (26)$$

We recall from (6) that the condition of economic feasibility of the investment in a *single* factory is,

$$t_1 > 2\left(\frac{F}{\bar{x}^2}\right)$$

By comparing both economic feasibility conditions, we find out that in either case industrial investment is eased by a high overall transport cost level (as measured by t_1)in relation to the importance of scale economies (expressed by the ratio $\frac{F}{\bar{x}^2}$), which in turn varies inversely to the size of economy.

In addition, inequality (26) means that manufacturing decentralization is facilitated by a high δ, i.e. by a strong gain in output transportability relative to the input during the industrial transformation.

We also notice that condition (26) is more restrictive that the related inequality for a single plant, as $\frac{4-\delta}{\delta} > 2for0 < \delta < 1$.

Proposition 2 summarizes the results obtained so far.

Proposition 2. . If the refining rate is high enough ($\delta \geq \frac{1}{2}$)**,** then, the structural change of the economy can be described as

- If $t_1 < 2(\frac{F}{\bar{x}^2})$, the economy is not viable since no manufacturing activity can break even.
- If $2(\frac{F}{\bar{x}^2}) < t_1 < (\frac{4-\delta}{\delta})(\frac{F}{\bar{x}^2})$, the economy becomes viable, with a single refining plant located at the Town, in the context of a "monocentric" industrial structure.
- If$t_1 > (\frac{4-\delta}{\delta})(\frac{F}{\bar{x}^2})$, a second industrial plant is set up and located at a distance $\frac{2x}{4-\delta}$ from the Town, in the context of a "duocentric" industrial structure.

3.3. Graphical representation

It was noted above that, in this Von Thünen (1826)'s economy, each farmer chooses between two alternative activities. Either to deliver a raw product into Town, to be refined there and then exported ("activity 1″). Or to carry the farming commodity to a factory located in the countryside and then dispatch the refined and "lighter" output to Town to be exported ("activity 2″).

The bid rent curves of the two activities $Y_1(r)$and$Y_2(r)$ are as follows.

$$Y_1(r) = p - t_1 r \qquad 0 < r \leq \bar{r} \quad (27)$$

And

$$Y_2(r) = \begin{cases} \left[p - (t_1 + t_2)\hat{r}\right] + t_1 r & 0 < r \leq \hat{r} \\ \left[p + (t_1 - t_2)\hat{r}\right] - t_1 r & \hat{r} < r \leq \bar{r} \end{cases} \quad (28)$$

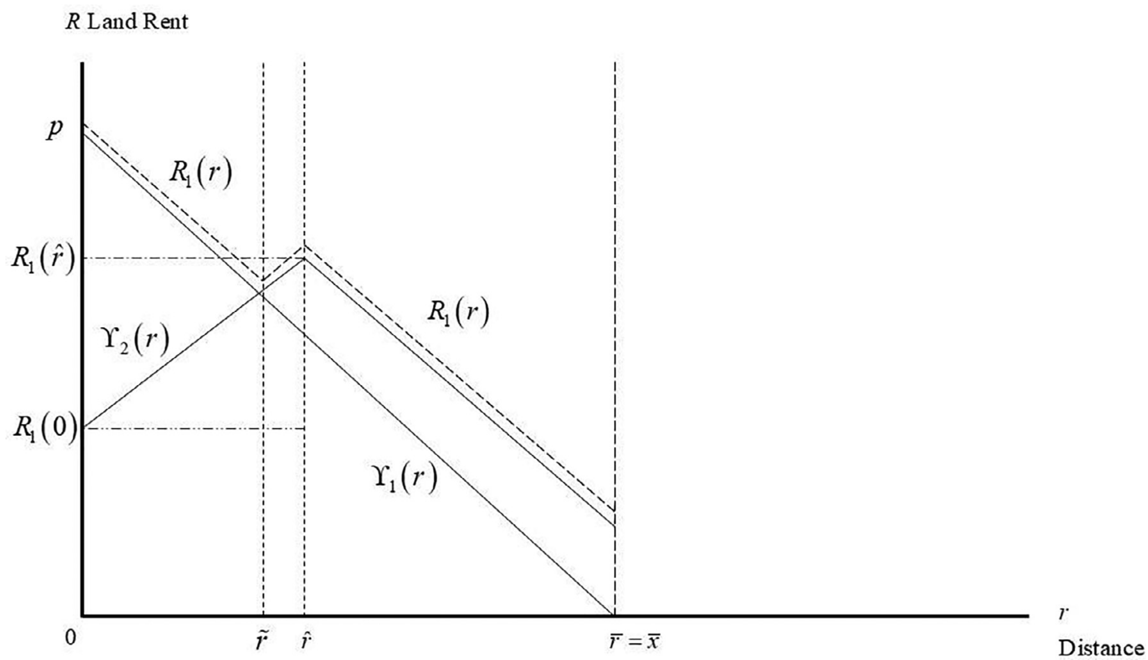

Fig. 3. Land rent curves under decentralized manufacturing.

The market land rent curve is as usual the upper envelope of the two bid rent curves. In each point r it is given by

$$R_1(r) = \max\{\Upsilon_1(r), \Upsilon_2(r)\} \tag{29}$$

We plot the bid rent curves and the market rent in Fig. 3.

Fig. 3 shows that producers that are close to the Town, such that $0 < r < \tilde{r}$, deliver the raw product in the Town to be processed and exported. Producers beyond point $\tilde{r}$ carry first the raw material to the factory in location $\hat{r}$ to be refined and then they transport it to the export terminal in $r = 0$.

The market rent curve is continuous, but it is not monotonic. Starting from the Town, it first decreases and then increases towards the factory location. It becomes again decreasing for locations beyond $\hat{r}$. The setting up of a decentralized manufacturing unit increases the land rent around it and such a rise helps to pay for the investment cost.

3.4. Comparison with an economy where "labor" is an intermediate good

In the line of Mills (1972, chapter 5), chapter 5), Ogawa and Fujita (1980) and Fujita and Ogawa (1982), this model might also describe the decentralization of a factory that transforms labor into a final consumer good. Instead of being regarded as "farmers", upstream producers are now rather viewed as "households" which produce the commodity "labor" by using residential land in a fixed proportion. "Labor" works in this context as an intermediate good, which is sold to manufacturers.

Unit transport costs $t_1$andt_2 stand within this framework for the commuting cost borne by a worker and for the manufactured good freight cost, respectively. The industrial transformation is "weight-losing" in this context, i.e., inequality $t_2 < t_1$ holds, because the mobility of products usually far exceeds the workers' ability to move in space.

The geographical pattern depicted in Fig. 2 means that individuals who live in the surroundings of the Town, in $0 < r < \tilde{r}$, commute there and find jobs in urban factories or at an export terminal. By contrast, individuals who live beyond point $\tilde{r}$ find more profitable to commute to the decentralized factory in $\hat{r}$. Then, a flow of products from the factory in the countryside to the urban export terminal substitutes for much more expensive commuting flows.

A special case arises whenever $t_2 \approx 0 \text{or} \delta \approx 1$. In this situation, rather than appearing as a plant, location $\hat{r}$ might be viewed in alternative as the site of a "secondary Town", endowed with its own export terminal. Workers commute to the nearest export terminal, either in $r = 0 \text{or} \hat{r}$, and help to produce a consumer good, which is then sold abroad from either urban center.

4. Concluding remarks

The model presented in this paper accounts for the main contemporary trends of manufacturing relocation.

Firstly, as inequality shows, economic development as measured by an increase in aggregate product $\bar{x}$ is directly associated with the decentralization of manufacturing. Factories are usually more agglomerated in developing countries than in industrialized economies.

Secondly, in the context of the so-called "deindustrialization", manufacturing plants tend to leave the regions that surround main urban centers. However, they usually refrain to settle in places that are "remote", i.e., that stay at a too long distance from the main centers of activity. Instead, relocating plants tend to prefer areas endowed with an intermediate level of accessibility relative to major metropolitan areas. By doing this choice, they make a compromise between two opposing forces. On the one hand, by staying at some distance from the Town, they make the refining, weight losing industrial process profitable, thus allowing the associated fixed costs of plant to be covered. On the other hand, they may not favor too remote locations, since each unit of product (either as a raw material or a manufactured good) must eventually be carried to the export terminal sited in the Town.

Finally, our paper helps to rationalize Krugman (2009)'s claim that *comparative advantage* based on relative factor abundance seems to have an increasing role for explaining the nature of international trade, by comparison with factors such as increasing returns to scale in relation to market size. Since trade liberalization falls mainly on manufactured goods, which form the bulk of trade, rather than on primary inputs, it works as if it raises the "refining rate" (parameter δ in our Proposition 2). Thus it creates a strong incentive for the setting up of a second factory away from the Town, whose location is driven by cost advantages consisting in the abundance of primary inputs, raw materials and labor.

Were trade costs of industrial products to rise, then parameter δ would fall, thus bringing about a centralization of manufacturing. The second factory would then become attracted to the market center and it could in the limit even merge with the incumbent urban plant. In this case, economies of scale would gain importance as a driving force of plant location.

Our inquiry has the disadvantage that it handles the decrease in output weight in relation to the input *for given fixed amounts of each good*. This was done for simplicity and it follows framework put forward by Von Thünen (1826) and Mills (1970; 1972, chapter 5).

Nevertheless, as List (1841), Launhardt (1885) and Dos Santos Ferreira and Thisse (1996) noticed, the decentralization of manufacturing not only reduces the output transport cost in relation to the input for fixed quantities of both goods, but it also expands significantly the demand addressed to the producers. Since the transformed product becomes lighter and easier to move, it is no longer bounded to be sold near the production site and can be exported at a larger scale.

The inclusion of the demand enhancing effect of industrial decentralization is left for future research. For that purpose, the Von Thünen (1826)'s economy should contain demand by consumers in the context of a general equilibrium model in the line of approaches such as those by Samuelson (1983) and Nerlove and Sadka (1991).

Conflict of interests

We declare that we do not have any conflict of interests to state.José Pedro Pontes and Armando J. Garcia Pires

Acknowledgements

The authors wish to thank the participants in a seminar held at CEF/Faculdade de Economia do Porto in 07/02/2020, where a former version of this paper was presented. They are grateful to the Editor of SCED and two anonymous referees.

This article was funded by UECE-REM (Research Unit on Complexity and Economics – Research in Economics and Mathematics), a research center of ISEG/Universidade de Lisboa. The authors acknowledge financial support from FCT – Fundação para a Ciência e Tecnologia (Portugal), national funding through research grant UIDB/05069/2020.

References

Cosar, A.K., Fajgelbaum, P.D., 2016. Internal geography, international trade and regional specialization. Am. Econ. J. 8 (1), 24–56.
Cournot, A., 1838. Recherches Sur Les Principes Mathématiques De La Richesse Sociale (3rd edition, 1974) s.l., Calmann-Lévy.
Dos Santos Ferreira, R., Thisse, J.-F., 1996. Horizontal and vertical differentiation – the Launhardt model. Int. J. Ind. Organ. 14, 485–506.
Eaton, J., Kortum, S., 2002. Technology, geography and trade. Econometrica 70 (5), 1741–1779.
Fujita, M., 2012. Thünen and the New Economic Geography". Reg. Sci. Urban Econ. 42, 907–912.
Fujita, M., Krugman, P., 1995. When is the economy monocentric? Von Thünen and Chamberlin unified. Reg. Sci. Urban Econ. 25, 505–528.
Fujita, M., Krugman, P., Venables, A., 1999. The Spatial Economy -Cities, Regions and International Trade. The MIT Press, Cambridge/Massachusetts and London/England.
Fujita, M., Ogawa, H., 1982. Multiple equilibria and structural transition of non–monocentric urban configuration. Reg. Sci. Urban Econ. 12 (2), 161–196.
Gaspar, JM., 2021. New economic geography: history and debate. Eur. J. Hist. Econ. Thought 28 (1), 46–82.
Helpman, E., 1998. The size of regions. In: Pines, D., Sadka, E., Zilcha, I. (Eds.), Topics in Public Economics: Theoretical and Applied Analysis. Cambridge University Press, Cambridge, pp. 33–54.
Harris, CD., 1954. The market as a factor in the localization of industry in the United States. Ann. Assoc. Am. Geogr. 44 (4), 315–348.
Henderson, J.V, Squires, T., Storeygard, A., Weil, D., 2018. The global distribution of economic activity: nature, history and the role of trade. Quart. J. Econ. 133 (1), 357–406.
Krugman, P., 1991. Increasing returns and economic geography. J. Polit. Econ. 99 (3), 483–499.
Krugman, P., 1993. First nature, second nature, and metropolitan location. J. Reg. Sci. 2, 33.
Krugman, P., 2009. The increasing returns revolution in trade and geography. Am. Econ. Rev. 99 (3), 561–571.
Launhardt, W., 1885. Mathematical Principles of Economics. Edward Elgar, London (English translation in 1993 of the first German edition).
Limão, N., Venables, A., 2001. Infrastructure, geographical disadvantage, transport costs and trade. World Bank Econ. Rev. 15 (3), 451–479.
List, F., 1841. Das nationale system der politischen okonomie. English translation, National System of Political Economy. Volume 2: The Theory. Cosimo, New York 2005.
Mills, ES., 1970. The efficiency of spatial competition. Pap. Proc. Reg. Sci. Assoc. 25, 71–82.
Mills, ES., 1972. Studies in the Structure of the Urban Economy, Baltimore and London. The John Hopkins Press.
Nerlove, ML., Sadka, E., 1991. Von Thünen's model of the dual economy. J. Econ. 54 (2), 97–123.
Ogawa, H., Fujita, M., 1980. Equilibrium land use pattern in a non-monocentric city. J. Reg. Sci. 20 (4), 455–475.
Pontes, J.P., 2019. Some stylized facts about deindustrialization in Europe. REM REM Working Paper 088–2019.
Ricardo, D., 1821. On the Principles of Political Economy and Taxation (edition of 1953). Cambridge University Press, Cambridge.
Rodrik, D., 2016. Premature deindustrialization. J. Econ. Growth 21 (1), 1–33.
Samuelson, PA., 1983. Thünen at two hundred. J. Econ. Lit. 21 (4), 1468–1488.
Spilimbergo, A., 1998. De-industrialization and trade. Rev. Int. Econ. 6 (3), 450–460.
Storeygard, A., 2016. Farther on down the road: transport costs, trade and urban growth in Sub-Saharan Africa. Rev. Econ. Stud. 83, 1263–1295.
Venables, AJ., Limão, N., 2002. Geographical disadvantage: a Hecksher-Ohlin- Von Thünen model of international specialization. J. Int. Econ. 58, 239–263.
Thünen, V., Heinrich, J., 1826. Der Isolierte Staat in Beziehung auf Landwirtschaft und Nationalokonomie. Oxford Pergamon Press, Hamburg, Perthes English translation by Carla M. Wartenberg (1966), Von Thunen's Isolated State.