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RESEARCH ARTICLE

# (De)Industrialization, Technology and Transportation

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**Abstract**
The transition from a traditional, constant returns technology to modern, increasing returns methods of production in manufacturing not only widens the scale of production but more crucially, it enhances product quality. Such a quality improvement consists mainly in a much higher level of transportability. The fact that products become "lighter" and easier to carry opens foreign markets to manufacturers thereby supporting larger scales of production. We model this situation through a one-stage game where firms distributed across two countries select technologies and *fob mill prices*. Contrasting with the *Big Push* approach, such a game is *never* a coordination game. In addition to cases where all firms adopt either modern or traditional technologies, the standard outcome is an asymmetric situation, where the modern firms in a country eliminate traditional units in the other country. Starting from a situation where all productive activity is traditional, deindustrialization can be viewed as a situation where firms in a country switch to more modern technologies while industrial units in the other country are unable to participate in this movement.

**Keywords** Deindustrialization · Technological development · Globalization · Transportation

**JEL Classification** F15 · F60 · O14 · R12 · R40

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## 1 Introduction

The growth of manufacturing in relation to overall productive activity has been viewed as a core factor of economic development. Since the seminal work of Rosentein-Rodan (1943) and Murphy et al. (1989), industrialization has been described as the outcome of a coordination process among industrial units that are concentrated within a well-defined geographical area (a nation or a region). These firms are assumed to have a small scale and use traditional, constant returns from the start. Each firm cannot switch individually to a modern technology entailing scale economies since the related increase in output would not be matched by an equally sized rise in demand. However, if all firms change their technology simultaneously, aggregate productivity will rise leading to the increase of wages and profits. Higher individual incomes raise the overall demand for manufactured products, thereby allowing each firm investing in increasing returns technology to break even.

Such model of industrialization is usually named as the *Big Push* and it has been developed in the literature (see, among others, Matsuyama 1992; Wang and Xie 2004; Daido and Tabata 2013). It shows two main features. Firstly, with the exception of Rodrik (1996), who regards coordination among firms as necessary condition of enhancing the country participation in international trade, it concerns a rather closed economy. The linkages resulting from the coordination among the investments by firms are by its nature *local* and concern neighboring firms. Secondly, it presupposes in all cases a coordination situation, with two possible *symmetric* outcomes – either all firms invest in new technology or none does it.

This paper yields an approach to industrialization that departs from the *Big Push* on these two grounds. On the one hand, the growth in manufacturing output related with the change in technology is now matched by an increase of foreign demand, rather than by localized demand linkages. On the other hand, although symmetric outcomes might happen, the typical situation consists in firms adopting *asymmetric* technologies, in the context of a "war game" (usually known as the "Chicken game") instead of the usual "coordination game".

In order to achieve this aim, we follow a strand of literature formed by early German economists, such as Von Thünen (1826), List (1841) and Launhardt (1885), which was continued more recently by Dos Santos Ferreira and Thisse (1996). These authors viewed the transition to modern, increasing returns technology by manufacturers as leading not only to an increase in the quantity of output but more crucially an enhancement of its *quality*. According to these authors, a better product quality essentially means that commodities become "lighter" and easier to carry in space. The rise in product transportability causes a surge in exports, the expansion of foreign demand thus allowing to absorb the increase in supply related with large scale production.

In this sense, our paper is also related with the literature in de-industrialization. This literature has shown that since the 1970s, advanced economies have experienced a secular decline in manufacturing as share of GDP.[1] Two main hypotheses have been put forward to explain this stylized fact: technology and globalization.

[1] For empirical evidence, see for instance Singh (1977), Crafts (1996), Saeger (1997), Kucera and Milberg (2003), Dasgupta and Singh (2006), Nickell et al. (2008), Buera and Kaboski (2009), Lawrence and Edwards (2013), Brakman et al. (2015), Rodrik (2016), Bernard et al. (2017) and Kang (2017).

The technological explanation (or the "relative productivity" hypothesis) says that deindustrialization is a consequence of increased productivity in manufacturing (see for instance Corden and Neary 1982; Rowthorn and Ramaswamy 1997, 1999; Matsuyama 2009; Tregenna 2011; Palma 2014). Accordingly, growth in manufacturing productivity leads to relative price changes and shifts in the structure of the economy. In particular, these changes conduce to a decrease in the share of manufacturing and an increase in the share of services in the economy.

In turn, the globalization explanation argues that deindustrialization is a consequence of a decrease in trade and transportation costs (see for instance, Rowthorn and Wells 1987; Rowthorn and Coutts 2004; Spilimbergo 1998; Shafaeddin 2005; Autor and Dorn 2013, Autor et al. 2013, 2014; Pierce and Schott 2016). Accordingly, as the costs of transporting goods in space decline, manufacturing has incentives to delocalize from high cost developed economies to more cost-effective developing economies.

In this paper, we follow the technological explanation, by arguing that technological progress leads to the production of goods that have lower production and transport costs.[2] We argue specifically that technological progress conduces to the development of products that are "lighter" to transport. Accordingly, production is a weight losing process, in the sense that transport costs represent a small share of the price for the output than for the input. This is so because production, whatever traditional or modern, adds value to the final good. In addition, modern technologies are more weight losing than traditional technologies since they add more value to final goods than traditional technologies. In this sense, even for the same value of transport costs, modern goods are less costly to transport in space than traditional goods. Globalization since it reduces transport costs rates, amplifies this "lightness" effect of modern technologies.

Glaeser and Kohlhase (2004), looking to the transport cost rates to different products for the US, show that in terms of value traded, manufacturing and technological products are more important than primary products (even when including oil products). The same is true if we consider value per ton. For instance, tobacco is the primary good with the highest value per ton of all primary goods, but still only about half of electronic products. In addition, if we consider shipping costs/value (both rail and truck), i.e. the "lightness" effect, the product with the lowest value is electronic products. This shows that manufacturing and technological products have lower transport cost per value added in relation to primary products. In our view, this evidence supports the results in our paper.

Furthermore, it is a well-known empirical fact that globalization has reduced transport costs, trade barriers and transportation costs, and that transportation costs increase with the weight of the good (see Hummels 2007). Hummels (2007), in addition and confirming Glaeser and Kohlhase (2004), provides evidence that besides the fixed rates of transport costs, it is also important to consider ad valorem transport costs: transport costs in relation to the monetary value of goods and services, i.e. the "lightness" effect. Hummels and Skiba (2004), for instance, estimate that a 10% increase in product price leads to an 8.6% fall in the ad-valorem transport cost. As Hummels and Skiba (2004) argue this means that

[2] Our inquiry is also related with "export-led growth" theories, starting with Pred (1966). It introduces in addition an endogenous determination of the size of the exporting sector within the overall economy.

transportation lowers the delivered price of high-quality goods relative to low-quality ones. Behrens et al. (2018) also show that transport costs also depend on the value of the good shipped. Accordingly, it is more profitable to ship expensive, high-quality, or high profit margin goods than less expensive, low quality, and low profit margin goods.

There is also some evidence that modern technologies are more weight losing than traditional technologies. The more obvious example is smartphones that contain several “appliances” from calculators, to cameras, to tape recorder, maps and many other things. Other way to see this is that the weight of mobile phones is smaller than the combined weight of a camera, a book with maps, a tape recorder, and so on.

Furthermore, the absolute weight of the average mobile phone has also been decreasing as, in 2011, the weight of mobile phones was one-sixth of what it was in 1990. The same occurs with other goods like computers, cars, and many electric and domestic appliances (see The Economist 2019). Furthermore, using data on America’s resource use, McAfee (2019) shows that the world economy has been moving beyond the “industrial era” of resource-heavy goods, implying that the latest computer age is making products that are much lighter and less material-intensive. Smil (2014) also shows that modern goods have become lighter and cheaper, which in turn have increased the demand for products.

In this sense when “lightness” effect is considered, the reduction in absolute transportation costs that we have assisted in the last century due to globalization is even more pronounced than if we just considered the fixed rates of transportation (see also Schott 2004; Tang 2006; and Harrigan 2010). As we have argued above, what is at play here is the “lightness” effect that modern technologies promote by adding more value to the goods than when they are produced with traditional technologies.

As a result of this “lightness” effect of modern technologies, we show that when goods are produced with traditional technologies (i.e. that do not add much value added to the final good), production needs to be located closer to consumption markets, in order to save on transport cost per unit of weight. In turn, when goods are produced with modern technologies, production can be profitably spatially decoupled from consumption, since the costs per unit of weight to transport goods are lower. It can be shown specifically that when goods become “lighter” to transport (because of technological progress), independently of absolute transportation rates, some regions/countries can experience deindustrialization.

In section 2, we model the process of industrialization/de-industrialization. In section 3, we discuss the results and draw the main conclusions.

## 2 A Model of (De)Industrialization

### 2.1 The Assumptions

We presuppose a spatial economy composed by two countries, *Home* and *Foreign*, which are completely symmetrical. Each country is populated by *n* consumers. As in Horstmann and Markusen (1992), each country can produce a homogeneous service good Z under constant returns to scale, with units chosen such that Z = L. Then Z or labor is numeraire. In addition, each country can also produce a homogenous consumer good. The focus of the model is in this good. The demand for the consumer good is inelastic, so that an individual is supposed to buy one unit of product per unit of time to the seller that charges the lower delivered price.

It is assumed that the productive activity of the consumer good is undertaken from the start in each country by a fringe of small competitive firms that operate under a constant returns technology. Each firm incurs a constant marginal cost $c$ and sells any quantity of output at the competitive price $p = c$.

One of the small firms has the option to switch to an increasing returns technology, thereby incurring a fixed cost $G$, which is related with the acquisition of a "machine". We assume that this machine fully depreciates during the current time period. The investment in fixed capital substitutes completely any variable inputs, so that the marginal constant cost becomes zero. If the firm achieves this structural change, then it becomes a monopolist thus eliminating all its rivals.

If the consumer good is produced under constant returns, it is a non-tradable commodity since the transport cost is presupposed to be arbitrarily high. By contrast, the monopolist's output exhibits a transport cost $t$ between the two countries, which is bounded from above. This assumption means that the productive activity is viewed as essentially weight-losing.

We can generalize this interpretation by considering *ad valorem* transport costs. Then, the loss of weight during industrial transformation can be observed in any value adding process, which yields an output that has a value per physical unit higher that the unit value of the input. In this case, the monetary transport cost represents a share of the price, which is usually much smaller for the output than for the input.

We also assume that the modern industrial firm charges a *fob mill price* whenever the consumer good is carried between the countries. Furthermore the monopolist is constrained to sell the output to any consumer at a delivered price not higher than the competitive price $p$, since otherwise it would be undercut by the local competitive fringe, which would then reenter the market. Hence, price $p = c$ behaves as a *limit delivered price* for the monopolist.

We presuppose that the monopolist distributes his output in both countries. Since he does not discriminate prices spatially, he charges the same *fob mill* price to every consumer, which should be slightly below $p - t = c - t$.

## 2.2 The Game-Theoretic Model

We can model this situation by means of a static, two-person game. The player in each country is the firm that can choose between using a constant returns technology within a whole competitive fringe (an action which we label as "Traditional") or switching to increasing returns to scale and become a monopolist (an action which we name as "Modern"). While under the former alternative of action, each firm sells a non-tradable output to domestic consumers only, under the latter strategy the modern monopolist firm is further able to export the consumer good.

The payoff matrix of this one-shot game, where one firm in each country decides to adopt either a "Traditional", constant returns or a "Modern", increasing returns technology is

$$\begin{array}{llcc} & & \text{Column} & \\ & & \text{Traditional} & \text{Modern} \\ \text{Row} & \text{Traditional} & a_{11}, b_{11} & a_{12}, b_{12} \\ & \text{Modern} & a_{21}, b_{21} & a_{22}, b_{22} \end{array} \tag{1}$$

where $a_{ij}$ and $b_{ij}$ are respectively the profits of players *Row* and *Column*.

Since the game is symmetric, we have $a_{ij} = b_{ji}$, and the payoff matrix (1) can be rewritten as

$$\begin{array}{llcc} & & \text{Column} & \\ & & \text{Traditional} & \text{Modern} \\ \text{Row} & \text{Traditional} & a_{11}, a_{11} & a_{12}, a_{21} \\ & \text{Modern} & a_{21}, a_{12} & a_{22}, a_{22} \end{array} \tag{2}$$

In order to find the equilibrium points in matrix (2), we only need to compute the best reply correspondence of a single player, i.e. of player *Row* without losing generality. Consequently, it is enough to include the payoffs of this player in the matrix, which thus becomes

$$\begin{array}{llcc} & & \text{Column} & \\ & & \text{Traditional} & \text{Modern} \\ \text{Row} & \text{Traditional} & a_{11} & a_{12} \\ & \text{Modern} & a_{21} & a_{22} \end{array} \tag{3}$$

The payoffs (profits) of Player (firm) *Row* in matrix (3) are

$$\begin{aligned} a_{11} &= a_{12} = 0 \\ a_{21} &\approx 2n(c-t)-G \\ a_{22} &= n(c-t)-G \end{aligned} \tag{4}$$

Then, the set of Nash equilibrium points in this $2 \times 2$ symmetric game is fully described in two Propositions.

**Proposition 1** The so called "coordination equilibrium", with two symmetric pure strategy equilibria (*Traditional, Traditional*) and (*Modern, Modern*) does never arise in the technology choice game.

**Proof** A symmetric strict Nash equilibrium in this game arises if and only if two conditions are satisfied.

Firstly, the outcome (*Traditional, Traditional*) should be a Nash equilibrium, i.e. for each player the strategy *Traditional* should be a best reply to the choice of *Traditional* by the opponent. This amounts to the inequality $a_{11} > a_{21}$ being satisfied. According to the definitions in (4), this is equivalent to

$$t + \frac{G}{2n} > c \tag{5}$$

Secondly, the result (*Modern, Modern*) should also be a strict Nash equilibrium. For each player the strategy *Modern* should be a best reply to the other player's decision to select *Modern*. Hence, the inequality $a_{22} > a_{12}$ should also be fulfilled, which is equivalent to

$$t + \frac{G}{n} < c \tag{6}$$

Clearly, inequalities (5) and (6) are inconsistent. *QED.*

This result is very important since it shows that our model of industrialization departs from the well-known *Big Push* models (such as Rosentein-Rodan 1943 and Murphy et al. 1989), where the "coordination equilibrium" is the typical result. In both types of approach, industrialization is viewed as process of technological mutation by a set of firms, which brings about a sharp rise in the output produced by each firm. The difference lies in the nature of the demand increase that matches the rise in manufacturing production. In *Big Push* models, such an increase of demand follows from *local demand linkages*, among neighboring firms located within a given geographical area. By contrast, in our view, the rise in demand stems from the technological mutation itself that leads to the production of commodities that are "lighter" and easier to carried. The fall in the product transport costs opens for each mutant firm the possibility to export its output thereby raising the demand addressed to each industrial plant.

Then, Proposition 2 describes the set of Nash equilibria in pure strategies of the condition under which each type of equilibrium may arise.

**Proposition 2** The game with payoffs described in (3) and (4) has the following set of Nash equilibria in pure strategies:

(i) *Traditional* is a (strictly) dominating strategy for each player if

$$t > c - \frac{G}{2n} \tag{7}$$

ii *Modern* is a (strictly) dominating strategy for each player if

$$t < c - \frac{G}{n} \tag{8}$$

iii There are two asymmetric Nash equilibria (*Traditional, Modern*) and (*Modern. Traditional*) if

$$c - \frac{G}{n} < t < c - \frac{G}{2n} \tag{9}$$

**Proof** A standard result in non-cooperative game theory (see among others Weibull 1997, chapter 1), is that in 2 × 2 symmetric games, such as the one described in (3) and (4), the set of possible strict Nash equilibria contains the following elements.

1 A strict dominant strategy equilibrium, *Traditional* being the dominant strategy.
2 A strict dominant strategy equilibrium, where *Modern* is the dominant strategy.
3 An asymmetric strict Nash equilibrium, where the equilibrium points are (*Traditional, Modern*) and (*Modern, Traditional*), which is the so called "Chicken" or "War Game".
4 A symmetric strict Nash equilibrium (*Traditional, Traditional*) and (*Modern, Modern*), which is the so called "coordination game".

We proved in Proposition 1 that a "coordination equilibrium" does never exist. Hence, we have only to assess the first three possibilities.

The strategy *Traditional* is strictly dominant if it is always a best reply, i.e. if the two following inequalities are satisfied.

$$\begin{aligned} a_{11} > a_{21} &\Leftrightarrow t > c - \frac{G}{2n} \\ a_{12} > a_{22} &\Leftrightarrow t > c - \frac{G}{n} \end{aligned} \tag{10}$$

Clearly, inequalities (10) are both satisfied if and only if $t > c - \frac{G}{2n}$.

The strategy *Modern* is strictly dominant if it is **always** a best reply, i.e. if the two following conditions are fulfilled.

$$\begin{aligned} a_{21} > a_{11} &\Leftrightarrow t < c - \frac{G}{2n} \\ a_{22} > a_{12} &\Leftrightarrow t < c - \frac{G}{n} \end{aligned} \tag{11}$$

The inequalities (11) are both satisfied if and only if $t < c - \frac{G}{n}$.

There are two strict asymmetric Nash equilibria (*Traditional, Modern*) and (*Modern, Traditional*). A precondition of this solution is that *Traditional* is a best reply to *Modern* and vice-versa. In this case, the best reply relations are

$$\begin{aligned} a_{21} > a_{11} &\Leftrightarrow t < c - \frac{G}{2n} \\ a_{12} > a_{22} &\Leftrightarrow t > c - \frac{G}{n} \end{aligned} \tag{12}$$

Hence, the asymmetric equilibrium outcome emerges for

$$t \in \left( c - \frac{G}{n}, c - \frac{G}{2n} \right) \tag{13}$$

*QED*

Proposition 2 tells that both firms adopt "modern" technologies if the gains in product transportability due to quality improvements are significant in relation to the rise in per capita fixed costs. Otherwise, both firms remain using a constant returns technology. In an intermediate case, a firm in one country switches to modern technology and the other one remains stuck with traditional productive methods. The latter case is the only one where a monopolist can export thereby eliminating the competitive traditional firms in the other country. Such a case with exports occurs more likely if scale economies are strong, as occurs when $\frac{G}{n}$ is high.

In the country that loses its industrial basis, we presuppose that former manufacturing workers are reallocated to the production of the service good, in the context of a process often labeled as "deindustrialization".

The situation where the consumer good is produced by a monopolist firm in each country becomes compatible with trade provided that we generalize the model assumptions in order to allow firms to engage in product differentiation. If the firms with modern technology in both countries produce heterogeneous commodities, then cross export flows might arise with each monopolist supplying both its domestic and foreign markets.

## 3 Discussion and Concluding Remarks

If the efficiency of the modern technology is low and the gains in product transportability are rather small, then parameter $t$ is very high and condition (7) is satisfied. The economy starts from a situation with a symmetric distribution of productive activity across the two countries with all firms using traditional, constant returns methods. Each country attains self-sufficiency in the production of the consumer good and no trade exists.

Let us presuppose now that modern technology becomes more efficient with the consumer good becoming "lighter" and easier to carry. If the fall in parameter $t$ is strong enough, then condition (7) ceases to be met and inequality (9) becomes prevailing instead. Industrial production is eliminated from one country and concentrates in the other country, where a transition from a traditional to a modern technology takes place. The former country experiments "deindustrialization", while modern manufacturing grows in the latter. The country that becomes industrialized exports its output and meets all the demand generated by the consumers living abroad. The country that suffers "deindustrialization" reallocates all its labor endowment to the production of the service good.

If product transportability is further increased and $t$ is additionally reduced, then condition (9) is no longer met and is replaced by inequality (8). Then, the country that previously did not host any manufacturing activity now industrializes using modern technologies so that increasing returns production exists in both countries. If we assume that consumer goods are differentiated then a two-way trade in heterogeneous products arises, with each country supplying both local and distant consumers.

This inverse U-shaped pattern of productive agglomeration as a function of transport costs behaves in the same way as the New Economic Geography result derived in Krugman and Venables (1995). However, while in Krugman and Venables (1995) this spatial pattern was due to intermediate goods trade, in here it is due to technological progress that produces good that are lighter to transport.

In our framework, deindustrialization of a country can be explained by a change in product transportability in two contrasting situations. On the one hand, if we depart from a situation where all firms use traditional technologies, the industrial demise of a country might follow from a global improvement in product quality, which the local firms do not manage to participate. On the other hand, starting from a situation where transport costs are low and technologies are modern everywhere, a rise in trade costs (whatever its origin) might lead to the concentration of all manufacturing within a country, the other country becoming deindustrialized.

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