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Offshoring Along the Production Chain

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Abstract

Recent contributions on offshoring often assume that firms can freely split their production process into separate steps which can be ranked according to the cost savings from producing abroad. We replace this assumption by the notion of a technologically determined sequence of production steps. In our model, cost savings from offshoring fluctuate along the production chain, and moving unfinished goods across borders causes transport costs. We show that, in such a setting, firms may refrain from offshoring even if relocating individual steps would be advantageous in terms of offshoring costs, or they may offshore (almost) the entire production chain to save transport costs. Small variations in model parameters may have a substantial impact on offshoring activities.

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1 Introduction

Over the past decade, significant attention has been devoted to the phenomenon of offshoring, i.e. the fact that firms exploit international cost differences by fragmenting their production process across national borders. The rising importance of offshoring has been supported by a number of factors: a strong decline in transportation costs, the fall of the iron curtain, widespread liberalization of FDI policies, and improvements in means of international communication through new information technologies. In many rich countries, this development has raised fears about potential job losses, declining wages, and rapid de-industrialization. In fact, the public discussion abounds with anecdotes about value-added chains spanning the entire globe and grim forecasts of rich countries eventually degenerating to mere trading centers for goods produced at low-cost locations.

Given this heightened public interest, it is of no surprise that an increasing number of researchers is exploring the determinants and consequences of firms' offshoring decisions. Beginning with the seminal contribution of Jones and Kierzkowski (1990), various attempts have been undertaken to analyze the implications of the "second unbundling" – i.e. the disintegration of the production process – in a coherent, yet tractable way.[1] Quite recently, Grossman and Rossi-Hansberg (2008) [henceforth denoted by GRH] proposed a model that has become very influential in this respect. In their approach, the production process consists of different "tasks" which are performed by various types of labor and which may be done at home or offshored to a foreign country.[2] Whether offshoring is advantageous depends both on international wage differentials and on task-specific iceberg costs, which reflect the frictions associated with transmitting information and monitoring foreign activities. The crucial assumption of the GRH-framework is that tasks may be ranked according to these costs such that there is a unique threshold which determines the extent of offshoring: at given wages, all tasks up to this threshold level are done abroad while the rest is performed at home. Changes in relative wages or in the costs of offshoring shift the extensive margin of offshoring. A decline in offshoring costs, for example, results in more tasks

[1] The term "second unbundling" goes back to Baldwin (2006) to distinguish the spatial fragmentation of production from trade in final goods. A short and necessarily selective list of contributions to the literature includes Jones and Kierzkowski (1990; 2001a; 2001b), Feenstra and Hanson (1996a; 1996b; 1997; 1999), Arndt (1997), Venables (1999), Glass and Saggi (2001), Jones (2000), Deardorff (2001b; 2001a), Kohler (2004), and Egger and Egger (2007).

[2] By using the term offshoring instead of international outsourcing we indicate that the geographical location of production is at the center of our interest while we abstract from the firms' make-or-buy decision.

being performed abroad.

While the approach of GRH provides an elegant framework to open the black box of production it neglects three important aspects of reality: First, in many industries technology determines the sequence of tasks or production steps such that a rearrangement according to offshoring costs alone seems implausible.[3] The panels for a car-body are first pressed, then joined together and then sprayed; an airplane is rewired before the seats can be attached; the production chain for microchips begins with making silicon from quartz, purifying the silicon in a second step before wafers are produced, microchips are built on these wafers, and, finally, wafers are cut apart; in the textile industry one first needs to produce cotton or wool, then to spin yarn before this yarn can be woven or knitted. All these steps follow each other and cannot be simply re-organised according to offshoring costs or other criteria. Second, performing a certain production step often requires the unfinished good or at least a component of it to be physically present: spraying a car is impossible without having the car-body in the factory, weaving fabric requires the yarn etc. Finally, moving these intermediate goods across borders is associated with significant costs, which encompass physical transport costs as well as the costs of uncertain or delayed delivery.

In this paper, we present a formal framework that incorporates these observations in a transparent and tractable fashion. We set up a stylized partial equilibrium model of an industry that applies a technology with a continuum of production steps each of which can be located in the home country or abroad. We deviate from the previous literature assuming that production steps have to be undertaken in a predetermined sequence, a production step always requires the physical presence of the unfinished good, and shipment of the unfinished good across borders causes transport costs.

To see why and how these deviating assumptions matter, suppose there exists a sequence of production steps, say A, B, C, D, and steps A and C can be done more cheaply abroad while the converse is true for production steps B and D. To offshore only steps A and C, production begins abroad with step A, then the unfinished good must be shipped shipped back to perform

[3]The difference between tasks and production steps is subtle, but important: GRH assign a task to a specific type of labor – i.e. there are "high-skilled tasks" and "low-skill-tasks". By contrast, the production steps we have in mind potentially employ various types of labor (as in Dixit and Grossman, 1982; Feenstra and Hanson, 1996a, 1997; Kohler, 2004). Offshoring of production steps imposes the technological requirement that certain tasks, each performed by one particular production factor, must be bundled together to a production step at one location. Offshoring of single tasks assumes, instead, that each single task can be performed at a certain location independent of where other tasks are performed.

step B at home, shipped abroad again for step C, and finally shipped back home to perform step D. If transport costs for the unfinished good at its various stages are large, then such a strategy of *partial offshoring* may not be profitable. But this does not necessarily imply that there is no offshoring at all. Instead, although in itself it is not worthwhile to offshore step B, the firm may relocate this production step as well because steps A and C are worthwhile to offshore and adding step B saves transport costs twice. We call such a strategy *full offshoring*.

The decision to offshore one particular step thus essentially depends on the profitability to offshore adjacent steps, which may result in a tendency to lump together several parts of the production chain in one location. The extent to which this happens depends on a range of industry-specific parameters characterizing the production process, transport costs, and offshoring costs. We thus combine the argument that "...offshoring is an industry-specific phenomenon, relating to the idiosyncratic way in which the value added process of certain industry may be sliced up, or fragmented, into different tasks" (Kohler, 2008, p. 11) with the concept of a technologically determined sequence of production steps. This has an immediate consequence for how the extent of offshoring in a particular industry reacts to parameter variations: our framework suggests that such changes may occur in the form of discretionary regime shifts. This contrasts with the GRH-model where a minor variation of exogenous parameters leads to a smooth adjustment of the number of tasks that are performed abroad. We obtain such a "catastrophic shift" between industry-specific offshoring regimes even though we assume a CRS-technology. The mere existence of transport costs combined with the predetermined sequence of production steps is sufficient to lump together production steps, causing an international bundling or unbundling of large chunks of a production chain at marginal changes of transport-, production-, or offshoring costs.

Our model thus not only offers an explanation for why different industries may have quite different fragmentation intensities even though factor cost differences and offshoring costs are not obviously different (see Geishecker and Görg, 2008). It also rationalizes a discrepancy between estimates of the "offshoring potential" for certain industrialized countries and the actual volume of offshoring activities. In our model, such a difference directly follows from the joint assumptions of sequential production and transport costs: despite a large offshoring potential in terms of relative cost advantages, firms may choose to perform certain production steps at a single location since they are firmly tied into a technologically determined production chain.

The remainder of the paper is structured as follows: The following section 2 describes the model, section 3 derives the offshoring pattern, comparative statics are performed in section 4, section 5 extends the model to analyze as to how a modularization of the production process and the presence of multiple foreign countries with heterogeneous cost structures influence offshoring, and section 6 concludes.

2 Model Setup

Consider a competitive firm in sector i which produces a homogeneous good under constant returns to scale. Technology consists of a continuum of production steps which can be offshored abroad to exploit factor cost differences.

Each production step in this industry combines high- and low-skilled labor. The input coefficients of production step t in industry i are denoted by $a_{ih}(t)$ for high-skilled labor and by $a_{il}(t)$ for low-skilled labour. Factor prices are exogenously given. We follow GRH in assuming identical factor intensities for each production step, i.e. $a_{is}(t) = a_{is}$, for $s = l, h$. If production takes place in a domestic plant, then unit factor costs of each production step t in industry i are given by $c_i(w_l, w_h) = a_{il} \cdot w_l + a_{ih} \cdot w_h$, where w_l, and w_h are the domestic wage rates for high- and low-skilled labor, respectively. For brevity, we will omit the arguments of c_i wherever applicable.

If production step t is offshored, then production costs are raised by offshoring costs of the iceberg-type, that is, foreign production costs are multiplied by the term $d_i(t) > 1$. This reflects the additional costs associated with performing step t in the foreign country (e.g. costs of communication between headquarter and production unit or supervision costs).[4] Without loss of generality we normalize unit factor costs abroad to $\bar{c}_i = 1$. The unit cost function of the offshored production step t in industry i is then given by $d_i(t)$.

We deviate from the previous literature with respect to the ordering of production steps. While existing models of offshoring generally assume that production steps can be lined up according to their offshoring costs, this may not be the case in reality.

Assumption 1 *There is a technically determined sequence t, in which production steps have to be processed one after the other.*

Our second crucial assumption is based on the notion that every production step requires the presence of the unfinished good produced at the

[4]Instead of assuming offshoring costs, we could also consider differences between the home and the foreign country with respect to total factor productivity. The term $d_i(t)$ then represents the productivity advantage of the home country relative to the foreign location with respect to performing production step t.

preceding step. While transportation is assumed to be costless within national borders, any international change of location is costly:

Assumption 2 *Any crossing of borders between two adjacent production steps is associated with constant costs T_i per goods unit.*

The variable T_i captures not only the costs arising from physical transportation, but also from the risk of delayed delivery. Note that the magnitude of T_i is independent of the stage of the production process.

To capture the idea that the costs of offshoring may go up and down along the production chain, we assume that $d_i(t)$ takes the form of a cosine function.[5]

Assumption 3 *Offshoring costs are given by $d_i(t) = A_i \cos(\alpha_i t) + B_i$, where $t \in [0; 2n_i\pi]$ and $B_i - A_i \geq 1$.*

The restriction on $B_i - A_i$ ensures that $d_i(t) \geq 1$ for all t – i.e., offshoring costs are always positive. Although the specific functional form for the offshoring costs may appear somewhat unfamiliar in the context of international production, its parameters have a straightforward and natural interpretation (see Figure 1): the shift parameter B_i determines *average* offshoring costs, i.e., if B_i is very high, the frictions associated with communication and supervision render offshoring relatively unattractive for the "average" production step. The amplitude A_i of the cost function reflects differences in offshoring costs between individual production steps. A high value of A_i implies a wide range between lowest and highest offshoring costs over the production chain. The parameter α_i specifies the period $(2\pi/\alpha_i)$ of the offshoring cost function. It determines how frequently offshoring costs of single production steps alternate around the average value of B_i along the production chain. If α_i is high, closely-linked production steps differ substantially in relative offshoring costs. Conversely, if α_i is low, the sets of adjacent production steps which are characterized by lower or higher than average offshoring costs are large, making it advantageous *ceteris paribus* to perform comparatively large chunks of the production process in one location (at home or abroad). Finally, n_i determines the total length of the production chain $2\pi n_i$, distinguishing production processes with many from those

[5] The choice to fix the foreign cost level while allowing the costs of delegation $d_i(t)$ to vary across production steps is inconsequential in our partial-equilibrium setup. We could as well have fixed offshoring costs and allowed factor costs to vary along the production process – with this variation being due to either changing input coefficients or a varying total factor productivity. Of course, when our model is extended to a general-equilibrium framework such distinctions may become important.

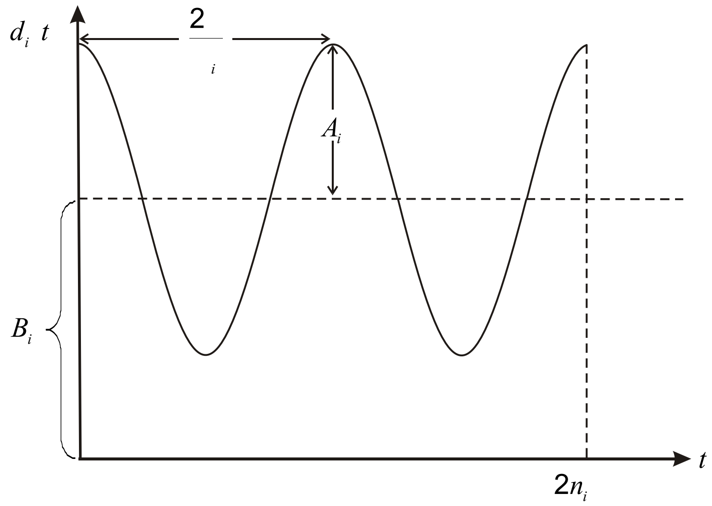

Figure 1: Offshoring Costs

with only a few production steps. To keep the analysis tractable while still being able to perform comparative-static analysis with respect to α_i and n_i, we assume $\alpha_i n_i \in \mathbb{N}^+$. The offshoring cost function $d_i(t)$ then exhibits $\alpha_i n_i$ full cycles. Different values of α_i or n_i thus imply different numbers of cycles while the overall shape of $d_i(t)$ for $t \in [0; 2n_i\pi]$ keeps being symmetric.

Hence, in addition to the transport cost T_i, we have four parameters to describe the technological environment of the offshoring decision. We later capture technological or institutional change by varying these parameters – by lowering average offshoring costs and the heterogeneity of these costs (lowering B_i and A_i, respectively), by allowing for an increased heterogeneity in the production process (raising α_i) or by changing the length of the production chain n_i.

Our last assumption anchors the production chain in the domestic economy.

Assumption 4 *The final product is sold in the home market.*

This assumption implies that firms have to ship their final input back home (at a cost T_i) even if they choose to perform all production steps abroad. Whether such a decision is profitable will be analyzed in the following section.

3 The Offshoring Decision

Given our specification of the offshoring cost curve, we may now characterize the offshoring decision. This is done in Figure 2. To make the model interesting we only consider the case $B_i - A_i < c_i < B_i + A_i$, i.e. both locations have a cost advantage for at least some production steps. Since $B_i - A_i \geq 1$ this also implies $c_i > 1$. Thus, we exclude factor price equalization by assumption.[6] Given that the $d_i(t)$-function exhibits $\alpha_i n_i$ full cycles in the interval $[0, 2n_i\pi]$ we can define the set of *critical production steps* $(t^*_{1i}, ..., t^*_{mi})$ where the offshoring costs exactly offset the factor cost savings abroad; i.e. where $d_i\left(t^*_{ji}\right) = c_i$. This set is determined by

$$t^*_{1i} = \frac{1}{\alpha_i} \arccos\left(\frac{c_i - B_i}{A_i}\right) \tag{1}$$

as well as

$$t^*_{ji} = (j-1)\frac{\pi}{\alpha_i} + t^*_{1i} \quad \text{for} \quad j \in U \ , \quad \text{and} \quad t^*_{ji} = j\frac{\pi}{\alpha_i} - t^*_{1i}, \quad \text{for} \quad j \in E \ ,$$

where U are the uneven integers $\{1, 3, ..., m_i - 1\}$ and E the even integers $\{2, 4, ..., m_i\}$, with $m_i \equiv 2\alpha_i n_i$ representing the total number of critical production steps.

By the periodicity of the offshoring cost function $d_i(t)$ and the assumption concerning the parameter range of c_i, offshoring costs are lower than factor cost savings in the interval $\left(t^*_{ji}; t^*_{j+1,i}\right)$, $j \in U$, whereas offshoring costs are at least as high as factor cost savings along $[t^*_{ji}; t^*_{j+1,i}]$, $j \in E$, as well as at the beginning and the end of the production chain, i.e. in $[0; t^*_{1i}]$ and $[t^*_{m_i}; 2\pi n_i]$.

Figure 2 depicts the case of $m_i = 4$. For all steps in the interval $[0; t^*_{1i}]$ production costs abroad (including offshoring costs) are at least as high as domestic production costs. For all steps in $(t^*_{1i}; t^*_{2i})$ producing abroad is cheaper than producing at home, even if offshoring costs are taken into account. In the interval $[t^*_{2i}; t^*_{3i}]$ domestic production weakly dominates foreign production etc.

If there were no transport costs, the firm in sector i would obviously exploit all cost differences and produce abroad whenever $d_i(t) < c_i$. However, once the costs of shipping intermediate goods back and forth are strictly positive, the size of cost savings matters as well. We denote the total cost savings associated with offshoring the sequence $(t^*_{1i}; t^*_{2i})$ by D^-_i. It follows

[6] In general equilibrium, factor costs would be endogenous. A failure of international factor price equalization may then be the result of trade costs or different total factor productivities.

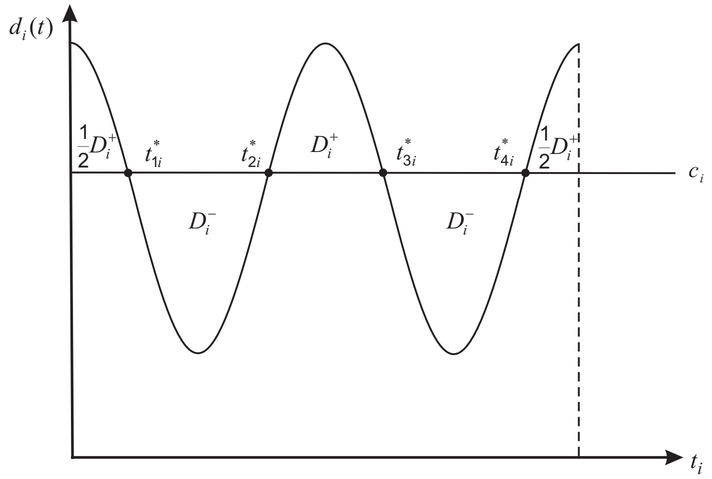

Figure 2: Cost Savings from Offshoring

from the symmetry of the cosine function that:

$$D_i^- = \int_{t_{1i}^*}^{t_{2i}^*} [c_i - d_i(t)]\, dt = \int_{t_{ji}^*}^{t_{j+1,i}^*} [c_i - d_i(t)]\, dt\ , \qquad \text{for } j \in U \tag{2}$$
$$= 2\left[\frac{A_i}{\alpha_i} \cdot \sin(\alpha_i t_{1i}^*) + (B_i - c_i)\left(t_{1i}^* - \frac{\pi}{\alpha_i}\right)\right] .$$

Taking the derivative of (2) with respect to t_{1i}^* and using (1), we can show that $\partial D_i^- / \partial t_{1i}^* = 0$: Offshoring additional production steps has no effect on cost savings D_i^- at the margin. Increasing the amplitude of the $d_i(t)$ function obviously increases D_i^-, i.e. $\partial D_i^- / \partial A_i > 0$. Moreover, $t_{1i}^* < \pi/\alpha_i$ implies that $\partial D_i^- / \partial B_i < 0$ and $\partial D_i^- / \partial c_i > 0$: higher average offshoring costs – reflected by an upward shift of the $d_i(t)$-curve – render offshoring less advantageous, whereas a higher factor cost-advantage of the foreign country – reflected by a higher value of c_i – has the opposite effect. To determine the influence of α_i on D_i^- we cannot simply look at the derivative, because $\alpha_i n_i$ is an integer. However, inserting t_{i1}^* into (2) shows that the product $\alpha_i\ D_i^-$ does not change in α_i, which means that D_i^- declines in α_i. Recall that a higher value of α_i reflects greater heterogeneity of adjacent production steps in terms of relative offshoring costs. Technically, raising α_i *ceteris paribus* raises the frequency of the $d_i(t)$-function, reduces the length of the interval $(t_{1i}^*; t_{2i}^*)$ and thus diminishes the cost savings associated with offshoring a sequence of production steps.

Likewise, the cost savings from performing production steps in the interval

$[t^*_{2i}; t^*_{3i}]$ at home are given by

$$D_i^+ = \int_{t^*_{2i}}^{t^*_{3i}} [d_i(t) - c_i]\, dt = \int_{t^*_{ji}}^{t^*_{j+1,i}} [d_i(t) - c_i]\, dt\ , \qquad \text{for } j \in U \tag{3}$$
$$= 2\left[\frac{A_i}{\alpha_i} \cdot \sin(\alpha_i t^*_{1i}) + (B_i - c_i)\, t^*_{1i}\right]\ ,$$

where we have exploited the fact that $(t^*_{3i} - t^*_{2i}) = 2t^*_{1i}$. As with D_i^- we can show that $\partial D_i^+/\partial t^*_{1i} = 0$ and that $\partial D_i^+/\partial A_i > 0$. Conversely, but for obvious reasons, $\partial D_i^+/\partial B_i > 0$ and $\partial D_i^+/\partial c_i < 0$. The influence of α_i on D_i^+ is strictly negative.

From (2) and (3) we obtain

$$D_i^- - D_i^+ = \frac{2\pi}{\alpha_i}(c_i - B_i)\ . \tag{4}$$

This equation compares cost savings from offshoring production segments for which the foreign country has lower unit costs with cost savings from leaving other segments with $d_i(t) > c_i$ at home. The cost difference $D_i^- - D_i^+$ is positive if and only if factor costs at home c_i exceed average offhoring costs B_i. For this case we can say that the foreign country has a *total cost advantage* to produce good i. Note, finally, that the absolute value of cost savings decreases in α_i: if the foreign country offers a cost advantage for "shorter" segments of the production process this reduces the relative benefits of offshoring these segments.

The last term to be determined is the cost advantage from producing the first or the last production sequence at home:

$$\int_0^{t^*_{1i}} [d_i(t) - c_i]\, dt = \int_{t_{m_i}}^{n_i\pi} [d_i(t) - c_i]\, dt = \frac{1}{2} D_i^+\ . \tag{5}$$

We can now turn to the offshoring decision of firms in sector i. Obviously, the last sequence $[t^*_{m_i}; 2n_i\pi]$ always takes place at home, because, first, it is cheaper to produce these steps at home and, second, the final good needs to be present at home by Assumption 4.

With respect to the other production steps we can distinguish the following **offshoring regimes**: no offshoring at all, full offshoring, and partial offshoring.

Definition 1 Full offshoring*: the sequence of production steps in the interval* $[0, t^*_{m_i})$ *is offshored.*

Definition 2 Partial offshoring*: the sequences of production steps in the intervals* $\bigcup_{j \in U} \left(t^*_{ji}; t^*_{j+1,i}\right)$ *are offshored.*

Full offshoring implies that all production steps except for the last sequence $[t^*_{m_i}; 2n_i\pi]$ are done abroad. Hence, it causes transport cost T_i only once for shipping the intermediate good back to the home country. Partial offshoring instead involves sending forth and back the good, wherever segments of the production chain are manufactured abroad. Hence, the unfinished good crosses the border $2m_i$ times in the production process. Because the offshoring cost function is symmetric, firms offshore all segments with $c_i > d_i(t)$ if it is worthwhile offshoring one of them. By the same type of argument we can exclude offshoring patterns other than no-, partial- or full offshoring.[7] For example, producing the first sequence $t \in [0, t^*_{i1}]$ at home gives a cost advantage of $D^+_i/2$ but raises transport costs by T. This is exactly half of the cost advantage and additional transport costs that would occur from producing a sequence $[t^*_{ji}; t^*_{j+1,i}]$, $j \in E$ at home. If partial offshoring is worthwile later in the production chain, it is so for the first sequence as well.

To determine the optimal offshoring pattern for a firm in sector i we simply have to compare costs under the three different regimes. If there is no offshoring, total costs C^n_i to produce one unit of the good are $C^n_i = 2\pi n_i c_i$. Cost savings from full offshoring compared to no offshoring $C^n_i - C^f_i$ are given by

$$C^n_i - C^f_i = \frac{m_i}{2} D^-_i - \frac{m_i - 1}{2} D^+_i - T_i \ . \tag{6}$$

These cost savings increase in D^-_i and decline in D^+_i and in the transport costs T_i. By setting $C^f_i = C^n_i$ we can determine a critical level of transport costs $T^{f,n}_i$ for which the cost advantage of full offshoring compared to no offshoring vanishes:

$$T^{f,n}_i \equiv \frac{1}{2} D^+_i + \frac{m_i}{2} \left(D^-_i - D^+_i\right) \ . \tag{7}$$

Cost savings from partial offshoring compared to no offshoring $C^n_i - C^p_i$ can be obtained as

$$C^n_i - C^p_i = \frac{m_i}{2} D^-_i - m_i T_i \ . \tag{8}$$

[7]To check for robustness of our results, we also have considered versions of our model in which the cosine function is shifted horizontally. Then the model may produce additional regimes with offshoring intervals differing from full offshoring as it is defined here. The basic insights of our model, however, remain: A partial offshoring regime exists for low transport costs whereas for higher transport costs the firm may offshore longer segments of the production chain.

This difference is positive as long as transport costs are below a critical value $T_i^{p,n}$, which is defined as

$$T_i^{p,n} \equiv \frac{1}{2} D_i^- \; . \tag{9}$$

Finally, the cost advantage from partial offshoring versus full offshoring is given by the condition

$$C_i^f - C_i^p = \frac{m_i - 1}{2} D_i^+ - (m_i - 1)\, T_i \; . \tag{10}$$

Partial offshoring saves costs compared to full offshoring as long as transport costs are below a critical value $T_i^{p,f}$, given by

$$T_i^{p,f} \equiv \frac{1}{2} D_i^+ \; . \tag{11}$$

We are now ready to lay out the choice of an offshoring regime for industry i in Proposition 1.[8]

Proposition 1 *Suppose Assumptions 1 to 4 hold. Then we can distinguish two cases:*

- Case 1: $c_i > B_i \Leftrightarrow T_i^{p,f} < T_i^{p,n} < T_i^{f,n}$.
  There is partial offshoring for $T_i < T_i^{p,f}$, full offshoring for $T_i^{p,f} < T_i \leq T_i^{f,n}$, and no offshoring for $T_i \geq T_i^{f,n}$.

- Case 2: $c_i \leq B_i \Leftrightarrow T_i^{p,f} \geq T_i^{p,n} \geq T_i^{f,n}$.
  There is partial offshoring for $T_i < T_i^{p,n}$ and no offshoring for $T_i \geq T_i^{p,n}$.

Proof. The ordering of the critical values of T_i for $c_i > B_i$ and $c_i \leq B_i$ can be established from (7), (9) and (11). The results of Proposition 1 then follow immediately. ■

Figure 3 illustrates Proposition 1 by depicting the cost differences $C_i^n - C_i^p$ and $C_i^n - C_i^f$ as functions of the transport costs T_i. The line $C_i^n - C_i^p$ is steeper than $C_i^n - C_i^f$, and its intercept with the ordinate is higher. Both lines therefore intersect, making either partial or full offshoring more attractive (to the left or right of this intersection). Figure 3.a represents Case 1, where the intersection $T_i^{p,f}$ is in the first quadrant, implying a positive cost advantage compared to no offshoring. In this case, we can distinguish three areas: partial offshoring for low transport costs T_i, full offshoring for intermediate T_i and no offshoring for high transport costs. In Case 2 (Figure 3.b) the lines

[8] In Proposition 1 we assume that the firm chooses the offshoring mode associated with the lowest transport activities whenever it is indifferent between several modes.

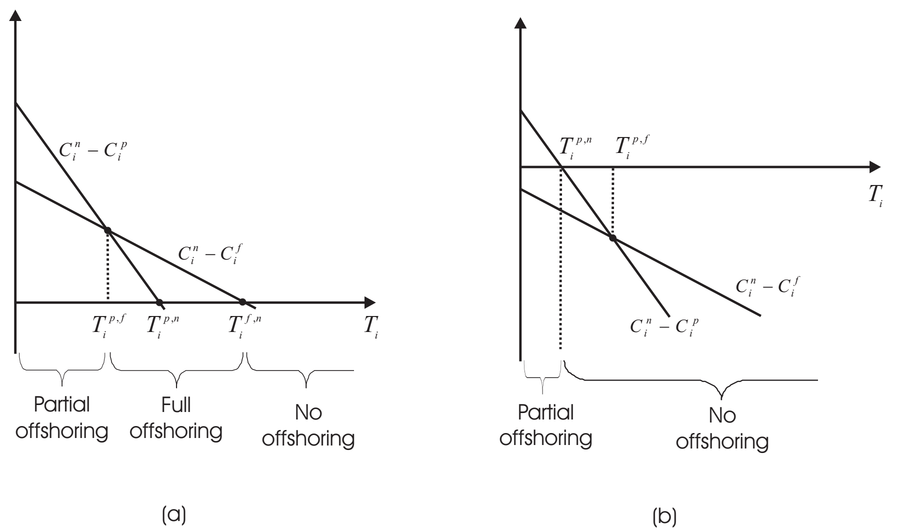

Figure 3: Partial and Full Offshoring

$C_i^n - C_i^p$ and $C_i^n - C_i^f$ intersect in the fourth quadrant, such that the area of full offshoring vanishes.

The relationship between c_i and B_i that distinguishes the two cases in Proposition 1 is important since it determines whether the foreign country has a total cost advantage or not: if $c_i > B_i$ this is the case and *full offshoring* becomes attractive once transport costs decrease below the critical threshold $T_i^{f,n}$. Conversely, if $c_i \leq B_i$ the factor cost advantage of the foreign country is too small to make up for the offshoring costs on average. This excludes full offshoring and induces firms to choose the *partial offshoring* regime once transport costs are sufficiently low – i.e. smaller than $T_i^{p,n}$.

Proposition 1 reveals that offshoring activities may change in a catastrophic way if certain transport cost thresholds are passed. Note that for this result we do not assume network effects or agglomeration economies Moreover, in Case 1, a hump-shaped pattern of offshoring activities emerges: As transport costs decrease, there is first a large increase in offshoring activities as the sector moves from no offshoring to full offshoring. At a further reduction of transport costs the offshoring volume declines again while switching to the partial offshoring regime.[9]

[9]For a related result in the context of a two-stage production process see Barba Navaretti and Venables (2004).

4 Comparative-Static Analysis

We are now ready to determine the influence of our model parameters on the offshoring pattern. Apparently, these parameters have consequences for both the critical transport costs which separate the different offshoring-regimes and the international allocation of production steps within a given regime.

We start by considering the extent of offshoring given that the sector is in a certain offshoring regime. The empirical literature measures the extent of offshoring as production value of intermediate inputs from abroad relative to total production value (e.g. Feenstra and Hanson, 1996b, 1999). In our framework, the length of the interval $\left(t_j^*, t_{j+1}^*\right)$, $j \in U$ multiplied by $\alpha_i n_i$ reflects this extent of offshoring. Setting this interval in relation to the length of the entire production chain $2\pi n_i$, we may determine the share of foreign production s_i^p in the *partial offshoring* regime as

$$s_i^p = \frac{\alpha_i n_i}{2\pi n_i}\left(t_{2i}^* - t_{1i}^*\right) = 1 - \frac{1}{\pi}\arccos\left(\frac{c_i - B_i}{A_i}\right) . \tag{12}$$

With *full offshoring* the respective share s_i^f is given by

$$s_i^f = \frac{t_{mi}^*}{2\pi n_i} = 1 - \frac{1}{2\alpha_i n_i \pi}\arccos\left(\frac{c_i - B_i}{A_i}\right) . \tag{13}$$

From differentiating (12) or (13) we obtain the following comparative-static results:

Proposition 2 *Suppose sector i is in the partial or in the full offshoring regime. The share of production that is offshored rises in c_i and declines in B_i. Furthermore, it declines in A_i iff $c_i > B_i$. In the full offshoring regime the share of production that is offshored also rises in α_i and n_i.*

The influence of the domestic factor costs c_i and of the average offshoring cost B_i is straightforward.[10] For the effects of changing the amplitude A_i we have to distinguish whether the foreign country has a total cost advantage (Case 1, $c_i > B_i$) or not (Case 2, $c_i \leq B_i$). In case 1, an increase in the value of A_i, reflecting starker contrasts between total costs at home and abroad, lowers the extent of offshoring. In case 2, the opposite holds. Due to the symmetry of the function $d_i(t)$ the length n_i of the production chain (and similarly α_i) influences the share of foreign production only in the full offshoring regime. The longer the production chain and the higher

[10] Recall that the function $\arccos(x)$ decreases in x.

the frequency of the $d_i(t)$ function, the shorter is the last sequence which is produced at home relative to the total mass of tasks that are performed.

Apart from affecting the international allocation of production steps in the partial or the full offshoring regime, a change in the technological environment may also shift the regime borders of Figure 3 as summarized in the following proposition.

Proposition 3 *The critical transport costs depend on the model parameters as follows:*

- $T_i^{f,n}$ *increases in* c_i *and* A_i *and declines in* B_i *and* α_i*. It also increases in* n_i *iff* $c_i > B_i$*.*
- $T_i^{p,n}$ *increases in* c_i *and* A_i *and declines in* B_i *and* α_i*.*
- $T_i^{p,f}$ *increases in* B_i *and* A_i *and declines in* c_i *and* α_i*.*

Proof. The results can be obtained from (7), (9), and (11) and the influence of the exogenous variables on (2) and (3). ■

Interpreting these results, we begin with the influence of the average offshoring costs B_i. In addition to a reduction in transport costs T_i globalization may materialize in a decline in B_i: a general improvement of communication and information technologies lowers average offshoring costs and thereby shifts the $d_i(t)$ curve downward. According to Proposition 3 full offshoring then becomes more attractive compared to both alternatives, partial offshoring and no offshoring. The range of transport costs that yields full offshoring in Figure 3.a increases. For $c_i \leq B_i$, (Figure 3.b) we have to compare partial offshoring with no offshoring. Partial offshoring becomes more advantageous for a larger range of transport costs if B_i declines. Thus, a decline in average offshoring costs causes a tendency towards more offshoring – not only in terms of the number of tasks that are offshored within a certain regime but also in terms of a potential shift towards a regime with more offshoring.

Figure 4 depicts the combined influence of T_i and B_i on the regime borders. Partial offshoring only occurs if transport costs T_i are low and average offshoring costs are neither too large nor too small. If transport costs T_i are high, but average offshoring costs are low, firms prefer full offshoring. In all other cases there is no offshoring.[11]

[11] Note that the dividing lines for the regimes are generally not linear.

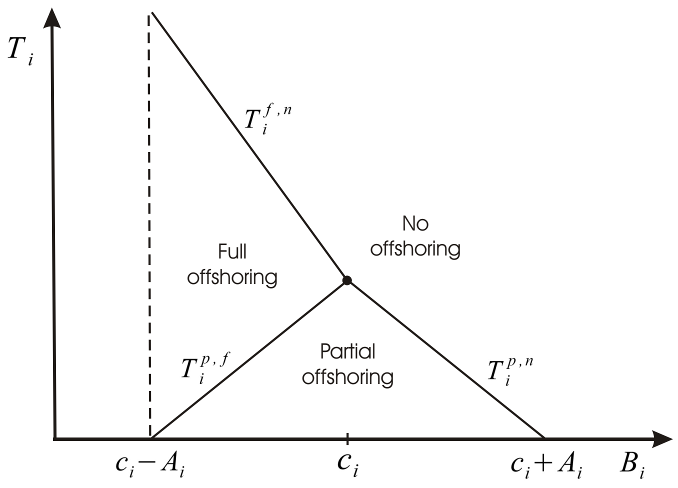

Figure 4: Offshoring Regimes

With respect to the other parameters, we see from Proposition 3 that an increase in the amplitude A_i or the period $2\pi/\alpha_i$ of the offshoring cost function raises all critical transport costs: as cost differences between adjacent production steps diminish and the size of potential cost savings increases, partial offshoring becomes more attractive at given costs of transportation. The length of the production chain n_i only influences the border $T_i^{f,n}$ between the full offshoring regime and no offshoring. The longer the production chain, the more attractive full offshoring becomes since the transport costs associated with repatriating the unfinished good before the final production segment become less important relative to potential cost savings.

5 Extensions: Modularization and Global Production Networks

5.1 Modularization

In the analysis so far we have taken the production chain for good i as non-divisible, i.e. a firm that decided to relocate a production step or a series of production steps had to ship the entire unfinished good to the plant in the foreign country and back. In most industries, however, the production process can be sub-divided into different components or modules that are manufactured individually and then assembled in a final production step. Our model can be easily extended to incorporate such a **modularization of production**. For this, we may view a component as a section of the

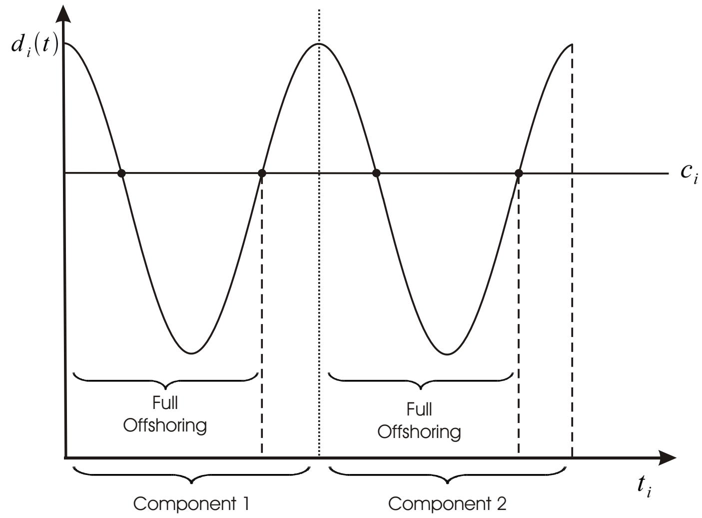

Figure 5: Modularization and Offshoring

total production chain that can be separated from other sections and manufactured individually. To keep our symmetric set-up, we assume that the production chain can be subdivided into k_i such sections of equal length (the components).Transport costs for each component are T_i/k_i, and the length of each segment is $2n_i\pi/k_i$. We furthermore assume that $n_i\alpha_i/k_i \in \mathbb{N}^+$, i.e. each segments covers one or multiples of a full cycle.

Modularization makes full offshoring more attractive compared to our baseline model as it breaks up the production chain. Some segments which can be produced cheaper at home now move to the end of the production chain. They can be produced at home as they are no longer captured between offshored segments in the middle of the production chain (Figure 5). Consequently, the critical transport cost $T_i^{f,n}$ increases and $T_i^{p,f}$ decreases in k_i:

$$T_i^{f,n} = \frac{k_i}{2} D_i^+ + \frac{m_i}{2}\left(D_i^- - D_i^+\right) \quad \text{and} \quad T_i^{p,f} = \frac{m_i - k_i}{2\left(m_i - 1\right)} D_i^+ \; . \qquad (14)$$

The range of transport costs which leads to full offshoring expands whereas the partial offshoring regime becomes smaller.

5.2 Global Production Networks

So far we have assumed that firms in the domestic economy may offshore production steps to a homogeneous "rest of the world". In reality, however, domestic producers face a multitude of foreign countries which differ substantially in terms of relative factor prices and offshoring costs, and they may exploit these differences by establishing **global production networks**.

To show how our framework can be modified to analyze this scenario we distinguish between two foreign countries ("country I" and "country II"). Without loss of generality we normalize factor costs in industry i to equal one in both countries. The offshoring cost function of industry i in country j is

$$d_i^j(t) = A_i^j \cos\left(\alpha_i^j t + \theta_i^j\right) + B_i^j \ , \tag{15}$$

with $j \in \{\mathrm{I}, \mathrm{II}\}$ and $\theta_i^j \in [0, 2\pi]$. To demonstrate the implications of this modification for offshoring patterns in the simplest possible framework we make the following assumptions: $A_i^j = A_i, \alpha_i^j = \alpha_i, B_i^j = B_i$ for both countries. Moreover, we set $\theta_i^I = 0$, $\theta_i^{II} = \pi$, and $B_i = c_i$,[12] and we assume that transport costs T_i are the same between all locations. Figure 6 depicts the resulting pattern of offshoring costs in countries I and II (relative to the domestic economy) for $m_i = 4$. Given the above assumptions, there is a perfectly negative correlation between the two countries' cost advantages: whenever country I offers lower costs, country II is at a disadvantage, and vice versa. Note, however, that we still stick to the assumption that the final good is sold in the domestic economy. Hence, if the last production step is performed in one of the two foreign countries, firms have to account for the costs of final shipping.

Given this setup, we may still distinguish between three offshoring regimes, however, the regime types now differ from our baseline model. The firm now produces in both foreign countries, and we call such a situation a "*global network*".[13] Depending on transport costs, the home country may be incorporated as a production site or not. More precisely, we may define a *partial* global network as a regime in which all production steps in the interval $[0, t^*_{m_i})$ are located abroad – in country I and country II – and the steps in the interval $[t^*_{m_i}, 2\pi n_i]$ are performed in the domestic economy. In a *full* global network, the firm produces entirely abroad in the two foreign countries. Note that the important difference between the two global network regimes is that a full global network requires one additional run of transportation, but allows the firm to save costs for a wider range of production steps.

[12]Note that the latter assumption implies $D_i^+ - D_i^- = 0$.

[13]Given our assumption $B_i = c$, it is never optimal for the firm to perform all production steps in a single foreign country.

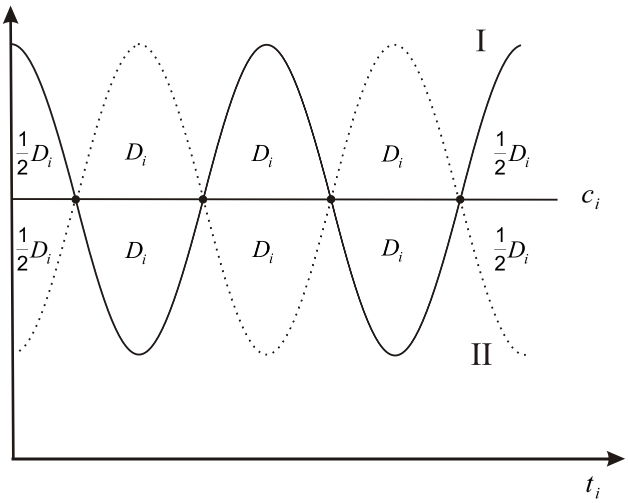

Figure 6: Offshoring Costs with Two Foreign Countries

Cost savings from a full and a partial global network are given by

$$C_i^n - C_i^{f,global} = m_i D_i^- - (m_i + 1)T_i \quad \text{and} \tag{16}$$

$$C_i^n - C_i^{p,global} = \left(m_i - \frac{1}{2}\right) D_i^- - m_i T_i \ , \tag{17}$$

where we have used the superscript *global* to indicate the presence of global production networks.

The cost differences as a function of T_i are depicted in Figure 7. As in the benchmark model, *no* offshoring is optimal for very high transport costs. As T_i decreases, a *partial* global network becomes preferable, i.e. firms shift a large part of the production process abroad, but the final sequence of steps is performed at home. As transportation costs decrease further, moving intermediate goods between countries is cheap enough to make a *full* global network optimal. Note that this result contrasts with the constellation derived in the benchmark model: There, decreasing costs of transportation eventually caused a shift to partial offshoring and a large share of production was performed in the domestic economy. By contrast, the possibility to establish a global production network and to exploit cost differences between *different* foreign countries leads to a dramatic increase in the offshoring volume once transport costs fall below a critical threshold.

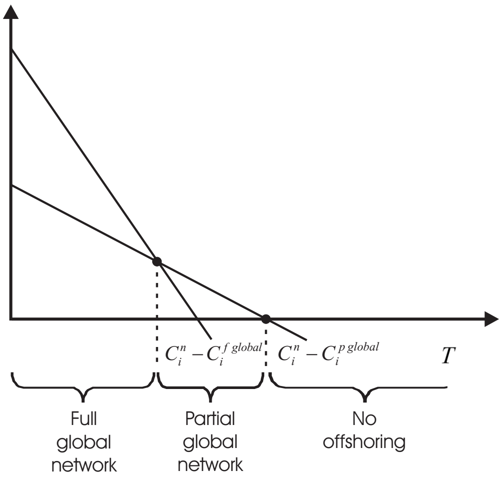

Figure 7: Global Production

6 Summary and Concluding Remarks

This paper has introduced a new approach to analyze firms' offshoring decisions. In contrast to existing models, in which single tasks or production steps can be arranged according to their offshoring costs, we have taken into account that, due to technological constraints, the sequence of production steps can rarely be varied at will. Combined with the plausible assumption that shifting intermediate goods between different locations is costly, this may lead to a clustering of individual production steps, such that the decision to produce a single step at home or abroad depends on the location of preceding or subsequent steps. In our framework, this leads to three different offshoring regimes: *partial*, *full* or *no offshoring*. We have shown that the borders between these regimes depend in a non-trivial way on costs of transportation and on offshoring costs. Thus, the influence of globalization – defined as improved international communication and reduced barriers to international trade – on the offshoring pattern is far from straightforward: on the one hand, firms may be reluctant to offshore certain production steps although, considered in isolation, these steps could be performed at far lower costs abroad. On the other hand, minor changes in the costs of offshoring or technological innovations affecting the structure of the production process may result in the relocation of considerable parts of the production chain all at once.

With regard to further advances in theory, the next logical step is to embed our offshoring model into a general equilibrium framework of international trade. We may then be able to obtain new insights into the relationship between the conditions for offshoring and factor rewards. Moreover, it should be possible to empirically test the implications of our approach. Our model suggests that one needs to take into account that various industries differ with respect to the "sequentiality" and potential modularization of their production chains, the size and relevance of transport costs, as well as the costs of relocating individual production steps. In our view, a firm grasp of these technological constraints holds the key for a better understanding of the extent and evolution of offshoring.

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