Harms, Philipp; Lorz, Jens Oliver; Urban, Dieter M.

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Offshoring along the production chain

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Offshoring along the Production Chain

PHILIPP HARMS
OLIVER LORZ
DIETER URBAN

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Offshoring along the Production Chain

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. Conversely, small variations in model parameters may lead to a large increase in offshoring activities.

JEL Code: D24, F10, F23.

Keywords: offshoring, international trade, vertical production chain.

Philipp Harms
RWTH Aachen University
Department of Economics and Business Administration
Templergraben 64
Germany - 52056 Aachen
harms@rwth-aachen.de

Oliver Lorz
RWTH Aachen University
Department of Economics and Business Administration
Templergraben 64
Germany - 52056 Aachen
lorz@rwth-aachen.de

Dieter Urban
RWTH Aachen University
Department of Business and Economics
Templergraben 64
Germany - 52064 Aachen
dieter.urban@wiwi.rwth-aachen.de

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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 strong decline in transportation costs, by the fall of the iron curtain, widespread liberalization of FDI policies, and by 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.\footnote{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).} 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.\footnote{GRH define offshoring as “...the performance of tasks in a country different from where the firm’s headquarters are located.” Conversely, “outsourcing” means “...the performance of tasks under some contractual arrangement by some unrelated party.” 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.} 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 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. 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.

In the GRH-model (or in related approaches like Kohler, 2004) physical transport costs do not matter for the decision whether to offshore a particular task, because tasks can be grouped together in any order by assumption.

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3The difference between tasks and production steps is subtle, but important (Kohler, 2008): 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 Feenstra and Hanson, 1996a,b, 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.
and physical transport takes place only once when an intermediate good consisting of the tasks (GRH) or production steps (Kohler, 2004) with the highest offshoring costs is produced at home and shipped abroad or conversely the tasks with the lowest offshoring costs are grouped together abroad and the resulting intermediate good shipped back home. Importantly, physical transport costs do not matter for the decision of whether to export one task or step more or less.

To see why and how the two 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 step B at home, shipped abroad again to perform 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 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 (Kohler, 2008) 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” in 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 the discrepancy highlighted by (Kohler, 2008) between the large “offshoring potential” identified by some studies and the rather moderate volume of offshoring activities that can be observed in practice. 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 home 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 how a modularization of the production process and the presence of multiple foreign countries with heterogeneous cost structures influences 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 Grossman and Rossi-Hansberg (2008) and Kohler (2008) 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

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\(^4\)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 $d_i(t)$
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.*

Production steps thus cannot be simply lined up according to their offshoring cost. Our second crucial assumption is based on the notion that every production step – including final sale – requires the presence of the intermediate good produced at the 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 the costs $d_i(t)$ 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 then represents the productivity advantage of the home country relative to the foreign location with respect to performing production step $t$.

\(^5\)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 variations 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.
(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. 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 term $\alpha_i$ 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 value chain. If this parameter is low, the sets of adjacent production steps which are characterized by lower or higher than average offshoring costs are rather large, making it advantageous \textit{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 with only a few production steps.

To keep the analysis tractable while still being able to perform comparative-static analysis with respect to $\alpha_i$ 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 $\alpha_i$ 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 $\alpha_i$) or by changing the length of the production chain $n_i$.

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

\textbf{Assumption 4} \textit{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.

\section{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
Figure 1: Offshoring Costs

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 on the interval $[0, 2 n_i \pi]$ we can define the set of critical production steps $(t^*_1, \ldots, t^*_{m_i})$ where the offshoring cost exactly offset the factor cost savings abroad; i.e. where $d_i(t^*_j) = c_i$. This set is determined by

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

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 $\{1, 3, \ldots, m_i - 1\}$ and $E$ the even integers $\{2, 4, \ldots, m_i\}$, with $m_i \equiv 2\alpha_i n_i$ as 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 cost are lower than factor\(^6\)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.

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cost savings on the interval \([t^*_j; t^*_{j+1,i}], j \in U\), whereas offshoring costs are higher than factor cost savings along \([t^*_j; t^*_{j+1,i}], j \in E\), as well as at the beginning and the end of the production chain, i.e. for \([0; t^*_{1i}]\) and \([t^*_{m_i}; 2\pi n\i\).

Figure 2 depicts the case of \(m_i = 4\). For all steps on the interval \([0; t^*_{1i}]\) production costs abroad (including offshoring costs) are at least as high as domestic production costs. For all steps in the open interval \([t^*_{1i}; t^*_{2i}]\) producing abroad is cheaper than producing at home, even if offshoring costs are taken into account. On 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 \(D^-\). It follows from the symmetry of the cosine function that:

\[
D^- = \int_{t^*_{1i}}^{t^*_{2i}} [c_i - d_i(t)] \, dt = \int_{t^*_{j_i}}^{t^*_{j+1,i}} [c_i - d_i(t)] \, dt, \quad \text{for } j \in U
\]

\[
= 2 \left[ \frac{A_i}{\alpha_i} \cdot \sin (\alpha_i t^*_{1i}) + (B_i - c_i) \left( t^*_{1i} - \frac{\pi}{\alpha_i} \right) \right].
\]

Taking the derivative of (2) with respect to \(t^*_{1i}\) and using (1), we can show
that \( \partial D^-_i / \partial t^*_i = 0 \): 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, \( t^*_i < \pi / \alpha_i \) 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 \( \alpha_i \) on \( D^-_i \) we cannot simply look at the derivative, because \( \alpha_i n_i \) is an integer. However, inserting \( t^*_i \) implies that the product \( \alpha_i \cdot D^-_i \) does not change in \( \alpha_i \), which means that \( D^-_i \) declines in \( \alpha_i \). Raising \( \alpha_i \) \textit{ceteris paribus} raises the frequency of the \( d_i(t) \)-function, reduces the length of the interval \( [t^*_1; t^*_2] \) and thus diminishes the cost savings associated with offshoring a sequence of production steps.

Likewise, the cost savings from performing production steps on the interval \( [t^*_2; t^*_3] \) at home are given by

\[
D^+_i = \int_{t^*_2}^{t^*_3} [d_i(t) - c_i] dt = \int_{t^*_j}^{t^*_j+1} [d_i(t) - c_i] dt, \quad \text{for } j \in U \quad (3)
\]

\[
= 2 \left[ \frac{A_i}{\alpha_i} \cdot \sin (\alpha_i t^*_1) + (B_i - c_i) t^*_1 \right],
\]

where we have exploited the fact that \( (t^*_3 - t^*_2) = 2t^*_1 \). As with \( D^-_i \) we can show that \( \partial D^+_i / \partial t^*_i = 0 \) 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 \( \alpha_i \) on \( D^+_i \) is strictly negative.

From (2) and (3) we obtain

\[
D^-_i - D^+_i = \frac{2\pi}{\alpha_i} (c_i - B_i). \quad (4)
\]

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 \( \alpha_i \): if the foreign country offers a cost advantage for “shorter” parts of the production process this reduces the relative benefits of offshoring.

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

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

Now we can 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 choices: no offshoring at all, full offshoring, and partial offshoring.

**Definition 1** Full offshoring: the sequence of production steps on the interval \([0, t_{m_i}^*]\) is offshored.

**Definition 2** Partial offshoring: the sequences of production steps on the intervals \( \bigcup_{j \in U} [t_{ji}^*; t_{j+1,i}^*] \) are offshored.

Full offshoring implies that all production steps except for the last sequence 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. For example, producing the first sequence \( t \in [0, t_{m_i}^*] \) at home gives a cost advantage of \( D_i + \frac{1}{2} D_i \) but raises transport costs by \( T_i \). 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 worthwhile 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 \( C_i^n \) to produce one unit of the good are \( C_i^n = 2 \pi n_i c_i \). Cost savings from full offshoring compared to no offshoring \( C_i^n - C_i^f \) are given by

\[
C_i^n - C_i^f = \frac{m_i}{2} D_i^- - \frac{m_i - 1}{2} D_i^+ - T_i \tag{6}
\]

These cost savings increase in \( D_i^- \) and decline in \( D_i^+ \) and in the transport costs \( T_i \). By setting \( C_i^f = C_i^n \) we can determine a critical level of transport
costs $T_{i}^{f,n}$ for which the cost advantage of full offshoring compared to no offshoring vanishes:

$$T_{i}^{f,n} = \frac{1}{2} D_{i}^{+} + \frac{m_{i}}{2} (D_{i}^{+} - D_{i}^{-}) . \quad (7)$$

Cost savings from partial offshoring compared to no offshoring $C_{i}^{n} - C_{i}^{p}$ can be obtained as

$$C_{i}^{n} - C_{i}^{p} = \frac{m_{i}}{2} D_{i}^{+} - m_{i} T_{i} . \quad (8)$$

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

$$T_{i}^{p,n} \equiv \frac{1}{2} D_{i}^{-} . \quad (9)$$

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

$$C_{i}^{f} - C_{i}^{p} = \frac{m_{i}}{2} D_{i}^{+} - (m_{i} - 1) T_{i} . \quad (10)$$

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

$$T_{i}^{p,f} \equiv \frac{1}{2} D_{i}^{+} . \quad (11)$$

We are now ready to lay out the optimal offshoring decision of industry $i$ in Proposition 1.\footnote{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.}

**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 $T$ 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. \qed
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 $T_{p,f}^i$ 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 $T$, full offshoring for intermediate $T$ and no offshoring for high transport costs. In Case 2 (Figure 3.b) the lines $C_i^n - C_i^p$ 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 $T_{f,n}^{i,p}$. 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 $T_{p,n}^{i,p}$.

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 as
in Baldwin (2006) or Robert-Nicoud (2008). 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 cost the offshoring volume declines again while switching to the partial offshoring regime.

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 \([t_j^*, t_{j+1}^*]\), \(j \in U\) 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 \(s_{fi}^p\) as

\[
s_{fi}^p = \frac{\alpha_i n_i}{2\pi n_i} (t_{i2}^* - t_{i1}^*) = 1 - \frac{1}{\pi} \arccos \left( \frac{c_i - B_i}{A_i} \right). \tag{12}
\]

With full offshoring the respective share \(s_{fi}^f\) is given by

\[
s_{fi}^f = \frac{t_{i1}^*}{2\pi n_i} = 1 - \frac{1}{2\alpha_i n_i \pi} \arccos \left( \frac{c_i - B_i}{A_i} \right). \tag{13}
\]

From differentiating (12) or (13) we obtain

**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 \(A_i\) if \(c_i > B_i\). In the full offshoring regime the share of production that is offshored also rises in \(\alpha_i\) and \(n_i\).

The influence of the domestic factor costs \(c_i\) and of the average offshoring cost \(B_i\) is straightforward. 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, \(c_i \leq B_i\)). The length \(n_i\) of the production chain (and similarly \(\alpha_i\)) influences the share of foreign production only in the
full offshoring regime. The longer the production chain, the smaller 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 $\alpha_i$. 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 $\alpha_i$.
- $T_{i}^p,f$ increases in $B_i$ and $A_i$ and declines in $c_i$ and $\alpha_i$.

**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 may begin with the influence of the average offshoring costs $B_i$. In addition to a reduction in transport costs 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 $B_i$. Partial offshoring only occurs if transport costs $T_i$ are low and average offshoring costs are neither too large nor too small. If both types of distance costs are small, the firm prefers full offshoring. In all other cases there is no offshoring.\(^8\)

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 costs raises

\(^8\)Note that the dividing lines for the regimes are generally not linear.
all critical transport costs. 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.

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. If the firm offshores a production step or a series of production steps, it has 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 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 \( k_i \) of 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 segment covers one or multiples of a full cycle.
Figure 5: Modularization and Offshoring

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 $T_{f,n}^{i}$ increases and $T_{p,f}^{i}$ decreases in $k_i$:}

$$T_{f,n}^{i} = \frac{k_i}{2}D_i^+ + \frac{m_i}{2}(D_i^- - D_i^+)$$  

and  

$$T_{p,f}^{i} = \frac{m_i - k_i}{2(m_i - 1)}D_i^+.$$  \hspace{1cm} (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 be one in both countries. The offshoring cost function of industry $i$ in country $j$ is

$$d^i_j(t) = A^i_j \cos(\alpha^i_j t + \theta^i_j) + B^i_j$$

with $j \in I, II$ 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 assume that $\theta^I_i = 0, \theta^{II}_i = \pi$ and $B_i = c_i$. Figure 6 depicts the resulting pattern of costs in countries I and II (relative to the domestic economy) for $m_i = 4$. Given our 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 type of regimes now differs from our baseline model. With two foreign countries, the firm may now produce in both foreign countries. We call such a situation a “global network”. Depending on transport costs, the

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$^9$Note that the latter assumption implies $D^I_i - D^I_i = 0$. 

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Figure 6: Offshoring Costs with Two Foreign Countries
home country may be incorporated as a production site or not. More precisely, we may define a partial global network as a regime where all production steps in the interval $[0, t^*_m]$ are located abroad – in country I or country II – and the steps on the interval $[t^*_m, 2\pi n_i]$ 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 wider range of production steps.

Cost savings from full and partial offshoring are given by

$$C^m_i - C^{f,global}_i = m_i D_i - (m_i + 1)T_i.$$  \hspace{1cm} (16)

where we have used the subscript $global$ to indicate the presence of global production networks.

$$C^m_i - C^{p,global}_i = \left(m_i - \frac{1}{2}\right) D_i - m_i T_i.$$  \hspace{1cm} (17)

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.

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10Given our assumption $B_i = c$, it is never optimal for the firm to perform all production steps in a single foreign country.
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 last sequence of steps is performed at home. As transportation costs decrease further, moving intermediate goods between low-cost countries is cheap enough to make a full global network optimal. Note that this result contrasts with the constellation derived in the benchmark model (case 1): there, decreasing costs of transportation eventually raised the share of production performed in the domestic economy. By contrast, the possibility to establish a “global production network” and to exploit cost differences between different foreign countries may lead to a dramatic increase in total offshoring once transport costs fall below a critical threshold.

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 costs of delegation. 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 delegation for 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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