

# The Supply Chain Structure Matters for Trade

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## Abstract

This paper investigates the role of supply chain structure on trade and offshoring patterns. We set up a three-country industry-equilibrium model in which firms can choose from different supply chain structures to produce their final goods. Our model provides three key results. First, we demonstrate that firms trade off coordination and trade costs when choosing their supply chain structure. Second, an industry-wide change in supply chain structure can lead to a wave of offshoring. Third, there is not necessarily a positive relation between the degree of offshoring and the amount of input trade.

**JEL Codes:** F23, F12.

**Key words:** supply chain, offshoring, international trade.

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*“The distinctive issues in international, as contrasted to domestic, strategy can be summarized in two key dimensions of how a firm competes internationally. The first is what I term the **configuration** of a firm’s activities worldwide, or where in the world each activity in the value chain is performed, including in how many places. The second dimension is what I term **coordination**, which refers to how like activities performed in different countries are coordinated with each other.”* — Porter (1986).

## 1 Introduction

The nature of trade has changed dramatically in the last few decades. Technological and institutional developments have allowed multinational firms to more easily slice up their value chains and disperse their production activities across the globe, thus leading to a remarkable increase in input trade (Feenstra, 1998; Hummels, Ishii and Yi, 2001).

These new trends in international trade have triggered a new field of theoretical research designed to better understand the organization of production across national borders. Starting with Jones and Kierzkowski (1990), a first branch of literature has focused on the determinants of international production fragmentation and the type of production activities that are offshored.<sup>1</sup> In this type of theoretical models, it is generally assumed that the production process for a particular good can be broken down into two exogenously specified sub-processes that differ in their relative factor usage or technology requirements. These sub-processes can be separated in space, albeit at extra trade and communication costs. It is then analyzed what the impact is of international production fragmentation on trade flows, welfare and factor prices.

More recently, a second branch of literature has combined the fragmentation literature’s technological setup with elements of the theory of incomplete contracts to analyze (i) when a firm chooses to be vertically integrated and when it chooses to outsource; and (ii) the role of institutions on the type of production activities offshored (see Spencer 2005 and Helpman 2006 for a review of this literature).

While the existing studies have gained key insights into the type of activities that are offshored and the ensuing welfare implications, its simplified technological setup cannot capture another key dimension related to the organization of international production: the coordination of international

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<sup>1</sup>Other notable studies are Jones and Kierzkowski (2001) and Deardorff (2001).

production activities (See Porter's (1986) quote above). To see this, assume that a final good firm can fragment its production process into three sub-processes and locate one sub-process in East, one in Center and one in West. In that case, a final good firm can coordinate its supply chain in two different ways (see Figure 1). First, he can import the inputs produced in East and West directly into Center for final good assembly. Second, he can organize his supply chain sequentially by first producing a set of inputs in East and exporting it to West; then producing a second set of inputs in West and sending the bundle of inputs from East and West to Center; and then finally assembling the final good in Center. Since trade and coordination costs are likely to differ in the two types of supply chain structures, the resulting trade and offshoring patterns may differ significantly depending on the supply chain structure adopted.

[Figure 1 about here]

In this paper, we set out to demonstrate how the supply chain matters for trade. For this purpose, we set up a simple three-country industry-equilibrium model in which final-good firms need to combine a continuum of inputs to produce a final good. They can choose from three types of supply chain structures to produce their final goods. First, they can produce all inputs domestically. Second, they can adopt a modular supply chain structure, which corresponds to the top scenario in Figure 1. Third, they can adopt a sequential supply structure, which corresponds to the bottom scenario in Figure 1. We find that final good firms face an interesting trade-off when choosing between a modular and a sequential supply chain structure: on the one hand a modular supply chain structure leads to higher coordination costs, on the other hand a sequential supply chain structure leads to extra trade costs. We investigate the implications of this supply chain choice on the equilibrium supply chain structure, as well as on trade and offshoring patterns.

This paper is organized as follows. Section 2 sets up the model. Section 3 then derives the equilibrium conditions for each supply chain structure separately, while Section 4 determines for which parameter range each supply chain structure is optimal. In Section 5, we will then discuss the implications of our model for trade and offshoring patterns. Finally, we summarize the model results in Section 6.

## 2 Model

Consider a simple three-country industry-equilibrium model in which  $n$  symmetric final-good firms decide how to organize their product's supply chain. Consumption of the industry's final goods is entirely concentrated in country Center ( $C$ ), where consumers spend a fixed fraction  $\xi$  of their aggregate income on the industry and have CES preferences for the industry's products:

$$U = \left( \int_0^n y(i)^\theta di \right)^{\frac{1}{\theta}}. \quad (1)$$

$y(i)$  is the quantity demanded of final good  $i$  and  $\theta \in [0, 1]$  is a parameter that determines the elasticity of demand. Consumer preferences given by equation (1) lead to the following demand function faced by the producer of good  $y(i)$ :

$$y(i) = Ap(i)^{-1/(1-\theta)}, \quad 0 < \theta < 1, \quad (2)$$

where  $p$  is the price of the good and

$$A = \frac{\xi}{np(i)^{\frac{-\theta}{1-\theta}}} \quad (3)$$

is the aggregate consumption index. We treat the number of firms as a continuum, implying that firms take  $A$  as given. To simplify notation, we from now on will drop the  $i$ 's.

Production of good  $y$  requires the firm to combine a continuum of differentiated inputs  $z$ , where  $z$  lies within the unit interval, i.e.,  $z \in [0, 1]$ . Each input can be produced in any of three countries East ( $E$ ), Center ( $C$ ) and West ( $W$ ). Inputs are produced with labor only and the industry is sufficiently small in each country so that firms take each country's unit labor cost schedule as given. Let  $b_m(z)$  be the unit labor cost in country  $m \in (C, E, W)$  for producing input  $z$ . A firm faces the following unit labor cost schedule for the three countries (see Figure 1 for a graphical representation of the unit labor cost schedule):

$$\begin{aligned} b_E(z) &= \alpha z & \text{for } z \in [0, 1] \\ b_C(z) &= \frac{\alpha}{2} - \alpha z & \text{for } z \in [0, \frac{1}{2}] \\ b_C(z) &= \frac{-\alpha}{2} + \alpha z & \text{for } z \in [\frac{1}{2}, 1] \\ b_W(z) &= \alpha - \alpha z & \text{for } z \in [0, 1] \end{aligned} \quad (4)$$

[Figure 2 about here]

As can be seen from Figure 2, the unit labor cost of producing inputs  $z \in [0, \frac{1}{4}]$  is lowest in East, of producing inputs  $z \in [\frac{1}{4}, \frac{3}{4}]$  is lowest in Center and of producing inputs  $z \in [\frac{3}{4}, 1]$  is lowest in West. This gives firms the incentive to take advantage of cost the differences by fragmenting production across borders.

When offshoring the production of inputs abroad, A firm faces both trade and coordination costs. Let  $\tau$  denote the trade cost of moving a unit of input between countries. In line with Anderson and Van Wincoop (2003), trade costs comprise not only transportation costs and tariffs, but also other trade costs. For simplicity, we assume in this model that  $\tau$  is identical between all pairs of countries and that  $\tau \leq \frac{\alpha}{4}$ .<sup>2</sup>

When coordinating activities across borders, we assume that a final good firm faces a fixed coordination cost  $\kappa^m$ , where  $m$  is the number of countries with which the downstream production node is simultaneously coordinating. We assume that  $\kappa \geq 2$ . This fixed coordination cost structure has two important implications. First, it implies that there are diseconomies of coordination when dealing with multiple production nodes. This is reasonable since one needs to switch from processing one kind of information to another. Second, it implies that a reduction in  $\kappa$  leads to a larger reduction in fixed cost when dealing with multiple suppliers.

The positive trade and coordination costs act as a disincentive to firms to move production offshore. Denote  $s_E \in [0, \frac{1}{2}]$  and  $s_W \in [0, \frac{1}{2}]$  as the share of inputs that are produced in the East and West, respectively. The unit marginal cost of production then depends on a final good firm's selection of  $s_E$  and  $s_W$ :

$$\begin{aligned}
&= \int_0^{s_E} \alpha z dz + \int_{s_E}^{\frac{1}{2}} \left( \frac{\alpha}{2} - \alpha z \right) dz + \int_{\frac{1}{2}}^{1-s_W} \left( -\frac{\alpha}{2} + \alpha z \right) dz + \\
&\quad \int_{1-s_W}^1 (\alpha - \alpha z) dz \\
&= \frac{\alpha}{2} \left( s_E^2 + s_W^2 + \left( \frac{1}{2} - s_E \right)^2 + \left( \frac{1}{2} - s_W \right)^2 \right)
\end{aligned} \tag{5}$$

In this model set up, the firm can organize its supply chain activities in three ways. First, he can concentrate its entire supply chain domestically (domestic production  $D$ ). Second, he can produce a portion of the inputs in the East and West and simultaneously import them to Center for final good assembly (modular supply chain  $M$ ). Finally, he can organize his supply chain sequentially by first producing a set of inputs in one country and exporting it to country two; then producing a second set of inputs in

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<sup>2</sup>The latter guarantees the feasibility of producing in three countries.

country 2 and sending the bundle of inputs produced in countries 1 and 2 on to Center (sequential supply chain  $T$ ).

When choosing between a modular and sequential supply chain, a final good firm faces an interesting trade-off: on the one hand, a sequential supply chain structure allows him to save on communication costs since  $2\kappa \leq \kappa^2$ . On the other hand, a modular supply chain structure allows him to save on trade costs since no inputs are traded more than once. As we shall see below, this trade-off will play a central role on our industry equilibrium determination.

Our model is characterized by two sequences of moves. In the first stage, final good firms choose their supply chain structure  $l \in \{D, M, T\}$ . In the second stage, they choose the share of inputs  $s_m$  to produce in each country  $m \in [E, C, W]$  and how many goods to produce. In our analysis below, we will solve for the optimal supply chain structure through backward induction.

### 3 Supply Chain Structures

We start off by determining firms' equilibrium behavior for each supply chain structure separately.

**Domestic Production.** Under domestic production, a final good firm sets  $s_E = s_W = 0$ , thus leading to the following cost-minimizing marginal production cost

$$\Psi^D = \frac{\alpha}{4}, \quad (6)$$

In his profit maximization problem, a final good firm chooses the amount of output that maximizes his profits  $\Pi = (p - \Psi^D) y - \chi$ , where  $\chi$  is the fixed cost of setting up a final good firm. It is straightforward to check that this program yields to the following optimal price for a final good firm:

$$p^D = \frac{\Psi^D}{\theta}. \quad (7)$$

Because the final good firm faces a constant elasticity of demand, the optimal price is equal to a constant markup  $1/\theta$  above marginal cost. Final good profits in turn are equal to

$$\Pi^D = A(1 - \theta) \left( \frac{\Psi^D}{\theta} \right)^{\frac{-\theta}{1-\theta}} - \chi. \quad (8)$$

Free entry and exit in the final good sector implies that all final good firms in industry equilibrium have zero profits. We can use the zero profit condition to derive the aggregate consumption index from equation (8).

$$A^D = \frac{\chi}{1-\theta} \left( \frac{\Psi^D}{\theta} \right)^{\frac{\theta}{1-\theta}} \quad (9)$$

We will use the aggregate consumption index  $A^D$  below to determine the equilibrium supply chain structure.

**Modular Supply Chain.** In a modular supply chain structure, a final good firm fragments its production internationally and produces  $s_E * y$  inputs in the East,  $s_W * y$  inputs in the West and the remaining inputs  $(1 - s_E - s_W)y$  in Center. He simultaneously imports the inputs produced in the East and West to the Center for final assembly. In this supply chain structure, the firm thus faces production cost  $\Omega(s_E, s_W)$  and trade cost  $(s_E + s_W)\tau$ . Since its activities in Center need to be coordinated simultaneously with the activities in both the East and West, he faces coordination cost  $\kappa^2$ .

A final good firm chooses the optimal combination of  $s_E$  and  $s_W$  to minimize its marginal cost  $\Psi = \Omega(s_E, s_W) + (s_E + s_W)\tau$ :

$$s_E^M = s_W^M = \frac{1}{4} - \frac{\tau}{2\alpha}. \quad (10)$$

Since the unit labor cost schedule of East and West is symmetric and since  $\tau$  is identical between all pairs of countries, it is intuitive that a final good firm chooses to produce the same share of inputs in both the East and West, where their share is increasing in  $\alpha$  and decreasing in  $\tau$ . Equation (10) implies that a final good firm faces the following marginal cost:

$$\Psi^M = \frac{\alpha}{8} + \frac{\tau}{2} \left( 1 - \frac{\tau}{\alpha} \right). \quad (11)$$

Taking into account this cost-minimizing marginal cost, a final good firm chooses output  $y$  that maximizes his profits  $\pi = (p - \Psi^M) y - \kappa^2 - \chi$ . Using the same steps as above, it is straightforward to check that profit maximization yields the following equilibrium aggregate consumption index under a modular supply chain structure:

$$A^M = \frac{\kappa^2 + \chi}{1-\theta} \left( \frac{\Psi^M}{\theta} \right)^{\frac{\theta}{1-\theta}}. \quad (12)$$

**Sequential Supply Chain.** In a sequential supply chain structure, a final good firm organizes its production process sequentially. Without loss of generality, he first produces inputs  $s_E * y$  in the East which he then exports to the West. He then produces inputs  $s_W * y$  in the West and exports  $(s_E + s_W)y$  to the Center. Finally, the remaining inputs are produced in Center and the final good is assembled. In this supply chain structure, trade costs amount to  $2s_E + s_W$  since the inputs produced in the East are traded twice. Coordination costs amount to  $2\kappa$  since the East and West only coordinate with one country during each sequence.

A final good firm minimizes its marginal cost  $\Psi = \Omega(s_E, s_W) + (2s_E + s_W)\tau$  by choosing  $s_E$  and  $s_W$ :

$$s_E^T = \frac{1}{4} - \frac{\tau}{\alpha}; \quad s_W^T = \frac{1}{4} - \frac{\tau}{2\alpha}. \quad (13)$$

Since inputs produced in the East face a higher transportation cost due to double shipment,  $s_E \leq s_W$ . A final good firm thus faces the following cost-minimizing marginal cost:

$$\Psi^T = \frac{\alpha}{8} + \frac{\tau}{4} \left( 3 - \frac{5\tau}{\alpha} \right). \quad (14)$$

Taking into account the cost-minimizing marginal cost, the final good firm chooses  $y$  to maximize his profits  $\pi = (p - \Psi^T)y - 2\kappa - \chi$ . Using the same steps as above, it is straightforward to check that profit-maximizing behavior yields the following equilibrium aggregate consumption index under a modular supply chain structure:

$$A^T = \frac{2\kappa + \chi}{1 - \theta} \left( \frac{\Psi^T}{\theta} \right)^{\frac{\theta}{1-\theta}} \quad (15)$$

**Comparison.** A comparison of the three supply chain structures demonstrates that they can be unambiguously ranked according to their fixed and marginal costs. Specifically, the marginal cost  $\Psi^l$  decreases as we go from domestic production ( $D$ ) to a sequential supply chain ( $T$ ) to a modular supply chain ( $M$ ). Inversely, the fixed cost increases as we go from domestic production ( $D$ ) to a sequential supply chain ( $T$ ) to a modular supply chain ( $M$ ).

## 4 Industry Equilibrium

For a supply chain structure to be pervasive in equilibrium, it must be the case that any firm with another supply chain structure faces negative profits

if it enters the market. In our model, any firm faces negative profits if the aggregate consumption index that it faces is lower than the equilibrium aggregate consumption index of its supply chain structure. This implies that the supply chain structure for who the aggregate consumption index is the lowest is the optimal supply chain structure.<sup>3</sup>

$$A^l = \min[A^l].$$

We can use this rule to determine the range of parameter values for which each organizational form is optimal. In figure 3, we depict the results of the analysis in  $(\tau, \kappa)$ -space.

[Figure 3 about here]

Figure 3 depicts three regions, each identifying the area in  $(\tau, \kappa)$ -space where the corresponding supply chain structure is optimal. The figure provides a number of results. A first obvious result is that domestic production is the optimal supply chain structure when both coordination costs  $\kappa$  and trade costs  $\tau$  are high. Second, in industries with a high  $\kappa$  and a small  $\tau$ , a sequential supply chain dominates; in industries with a small  $\kappa$  and a large  $\tau$ , a modular supply chain dominates. The reason behind this result is the inherent trade-off between coordination and transportation costs that occur in supply chain structures with more than two production nodes. This leads to the following proposition.

**Proposition 1** *A modular supply chain structure dominates in industries with relatively high trade costs and low coordination costs; a sequential supply chain structure dominates in industries with relatively low trade costs and high coordination costs.*

## 5 Trade and offshoring

We can analyze the impact of the supply chain structure on trade and offshoring patterns by calculating the degree of offshoring and trade for each supply chain structure.

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<sup>3</sup>See Grossman and Helpman (2002) and Van Assche (2007) for a similar determination of industry equilibrium.

**Offshoring.** The degree of offshoring  $d^l$  can be defined as the share of total labor cost that is produced in the East and West relative to the total labor cost:

$$d^l = \frac{\frac{\alpha}{2} (s_E^2 + s_W^2)}{\Omega[s_E, s_W]}$$

If  $d = 0$ , this implies that there is no offshoring. If  $d = 1$ , then everything is produced offshore. In our model, the degree of offshoring under the various supply chain structures equals

$$d^l = \begin{cases} 0 & \text{if domestic production} \\ \frac{\alpha^2 - 6\alpha\tau + 10\tau^2}{2\alpha^2 + 20\tau^2} & \text{if sequential supply chain} \\ \frac{(\alpha - 2\tau)^2}{2(\alpha^2 + 4\tau^2)} & \text{if modular supply chain} \end{cases} \quad (16)$$

It is straightforward to derive that the degree of offshoring rises as we go from domestic production ( $D$ ) to a sequential supply chain structure ( $T$ ) to a modular supply chain structure ( $M$ ). This leads to the following proposition:

**Proposition 2** *A reduction in coordination costs leads to a nonlinear increase in the degree of offshoring if it induces the industry to shift from a sequential to a modular supply chain structure. A reduction in trade costs leads to a nonlinear decrease in the degree of offshoring if it induces the industry to shift from a modular to a sequential supply chain structure.*

**Trade.** We can calculate the equilibrium amount of trade in a supply chain structure as the amount of input trade per final good multiplied by total industry output  $y * n$ . In the modular supply chain structure, this amounts to

$$(s_E + s_W)y * n = \frac{(4\alpha - 8\tau)\xi\theta}{\alpha^2 + 4\tau(\alpha - \tau)}. \quad (17)$$

In the sequential supply chain structure, the amount of trade is:

$$(2s_E + s_W)y * n = \frac{(6\alpha - 20\tau)\xi\theta}{\alpha^2 + 2\tau(3\alpha - 5\tau)}. \quad (18)$$

A comparison of both equations suggests that it is not clear-cut under which type of supply chain structure there is more trade. There will be more trade in the sequential supply chain structure than in the modular supply chain structure if the following condition holds:

$$\tau \leq \frac{\alpha}{8}(-3 + \sqrt{17}).$$

Otherwise, there is more trade in the modular supply chain structure. This ambiguity is due to the interaction of two factors. On the one hand, the amount of input trade that occurs for a single product is larger under a sequential supply chain structure than under a modular supply chain structure. On the other hand, the marginal cost of production is lower under a modular product architecture, thus implying that there are more final goods produced in the industry. The implication of this is that an increase in the degree of offshoring (through a shift from a sequential supply chain to a modular supply chain) does not necessarily go hand-in-hand with an increase in trade. We state it as the following proposition:

**Proposition 3** *An increase in the degree of offshoring does not necessarily lead to an increase in input trade.*

## 6 Conclusion

In this paper, we have set up a three-country industry equilibrium model to assess the role of supply chain structure on trade and offshoring. We find that final good firms face an interesting trade-off when choosing between types of supply chains: on the one hand, a modular supply chain saves on trade costs. On the other hand, a sequential supply chain saves on coordination costs. The trade-off implies that a modular supply chain structure dominates in industries with relatively high trade costs and low coordination costs, while a sequential supply chain structure dominates in industries with relatively low trade costs and high coordination costs.

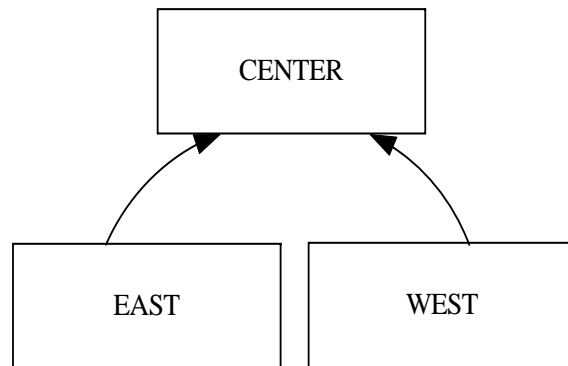
The extra trade cost under a sequential supply chain structure acts as a disincentive against offshoring. As a result, we find that the degree of offshoring under a sequential supply chain equilibrium is always smaller than under a modular supply chain equilibrium. This implies that a reduction in coordination costs can lead to a nonlinear increase in the degree of offshoring if it induces the industry to shift from a sequential to a modular supply chain structure. Similarly, a reduction in trade costs can lead to a nonlinear decrease in the degree of offshoring if it induces the industry to shift from a modular to a sequential supply chain structure.

Finally, we find that the amount of input trade is not necessarily larger under a sequential than a modular supply chain structure. This implies that, counter to the findings of the existing literature, there is not necessarily a positive relation between the degree of offshoring and the amount of input trade.

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MODULAR SUPPLY CHAIN STRUCTURE



SEQUENTIAL SUPPLY CHAIN STRUCTURE

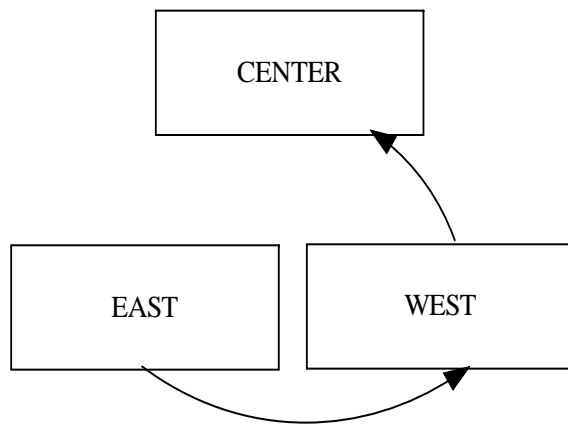


Figure 1: Modular versus Sequential Supply Chain

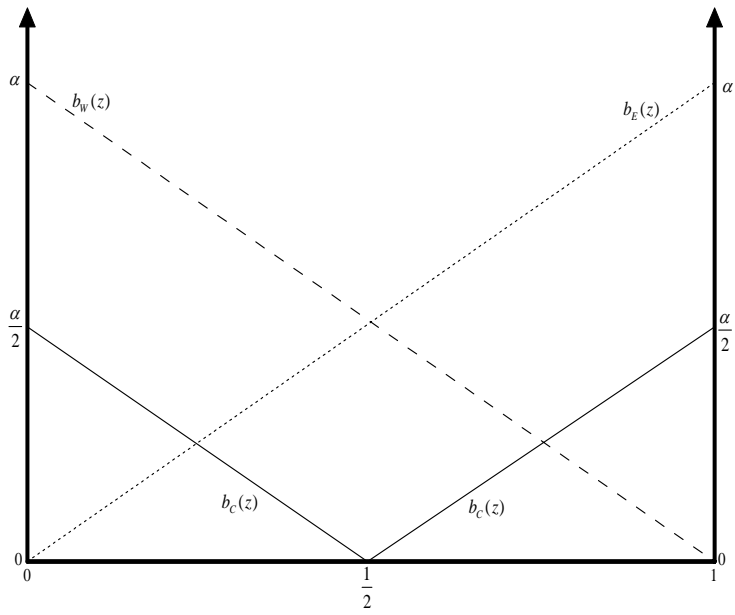


Figure 2: Unit labor cost schedule

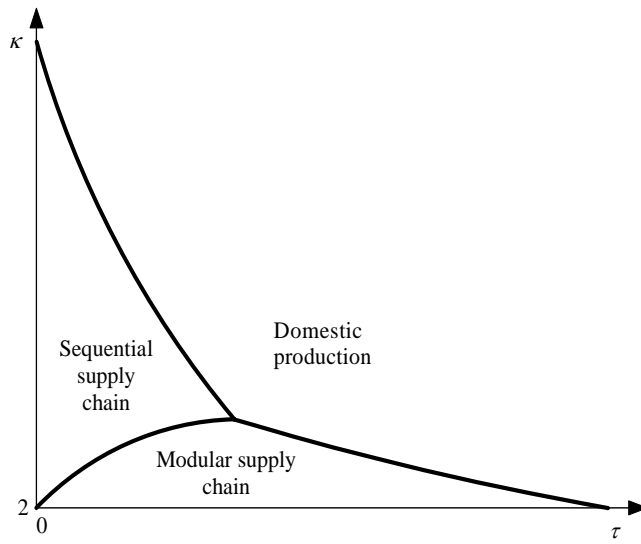


Figure 3: Optimal Supply Chain Structure