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Trade Facilitation and Supply Chain Network Design

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Abstract

World trade has expanded rapidly over the past decades. Low production costs in developing countries, along with cost efficient logistics networks have led to the allocation of manufacturing plants in offshore industrial sites. However, lengthy customs' clearance and service time delays and thus lengthy and highly variable lead times can undermine the efficiency of offshoring within global supply chain networks. Nearshoring, namely the practice of allocating manufacturing capacity next to the demand points, is a corporate response to such concerns. The purpose of this paper is to provide a quantitative strategic decision support methodology that captures the impact of the variability of order lead time demand on supply chain network design while further identifying: (i) the optimal mixture of nearshore/offshore production allocation capacity and (ii) the radius in the hinterland within which a global company can penetrate markets according to the entry point's customs efficiency. Various "what-if" analyses are conducted in order to explore the sensitivity of the production allocation mixture and the trade-off between travel distance and customs efficiency. The usage of the proposed methodology is demonstrated through its application on an appropriately simplified problem instance, while obtained managerial insights are discussed.

Keywords: *logistics network design, lead time variability, trade facilitation, transportation.*

1. Introduction

World trade has expanded rapidly over the past decades. Reduced traditional trade barriers in conjunction with low production costs in developing countries and cost efficient logistics networks have led to the allocation of manufacturing plants in offshore industrial sites. However, the practice of offshoring is efficient, only when goods are traded on time and with low transaction costs. Customs-related bottlenecks stemming from unnecessary and excessive data and documentation requirements, lack of co-ordination between customs and other inspection agencies, lack of modern customs techniques and inadequate transit regimes are a major setback for the efficiency of a country's logistics system, leading to excessive service and clearance times. Moreover, these bottlenecks lead to increased trade costs, which are developed as a direct function of collecting information and submitting declarations and as an indirect consequence of border checks in the form of delays and associated time penalties (Grainger, 2007).

Thus, the on-time and low-cost requirements have to be handled with efficient policies regarding non-tariff barriers to trade leading to trade facilitation. According to the European Commission (2010), trade facilitation can be defined as measures for the simplification and harmonisation of international trade procedures. It can improve the efficiency of a country's logistics system, which depends among others on its investments on logistics and information technology infrastructure, quality in customs management and procedures, corruption, etc., while reducing the associated trade costs.

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Although developed countries apply trade facilitation measures to improve the efficiency of their logistics systems, developing countries are still left behind. The World Bank (Arvis et al., 2007a, 2010) documented that even in developed countries waiting times and delays at customs are still significant. As a result, lengthy order lead times along with high customs clearance and service time delays, lead global companies to maintain strategic emergency stocks (Sheffi, 2001; Sheffi et al., 2003) as a "hedge" against stock-outs and lost sales. This stock captures the impact of risk at the strategic level of the supply chain network hierarchy and is used against irregularly high delays due to production or supply disruptions.

In this framework, lengthy and unpredictable transportation times along with high customs clearance and service times may undermine dramatically the efficiency of the offshoring practice. This systemic perspective has led managers to scrutinise the merit of new practices for supply chain network design. An outcome of such scrutiny is the practice of nearshoring that involves the allocation of the supply chain's capacity close to its serving markets (The Economist, 2005).

The purpose of this work is to propose a strategic decision support methodology for the design of globalised supply chain networks that will identify the optimal nearshore/offshore production allocation capacity and the radius in the hinterland within which a global company can penetrate according to the entry point's customs efficiency, while capturing the effect of the variability of the total order lead time demand on supply chain network design. Since it is quite challenging to capture the impact of trade facilitation-related bottlenecks on this strategic planning process, we employ the results of a comprehensive study conducted by the World Bank and its subsequent quantitative index, the Logistics Performance Index (LPI) (Arvis et al., 2007a, 2010).

The rest of the paper is organised as follows. In section 2, we provide a brief literature review, while in section 3 we describe the problem under study. In Section 4 we provide the developed methodological framework that captures quantitatively the impact of trade facilitation related parameters on supply chain design. In section 5 a numerical analysis is provided and obtained managerial insights are discussed. Finally, section 6 sums-up the findings of this research and provides future research directions.

2. Literature Review

The literature devoted to the strategic design of supply chain networks is quite extensive. The majority of research papers that handle strategic design of global supply chains involve profit maximisation models, which do not however capture the impact of variability and delays while crossing supply chain nodes (e.g. Vidal and Goetschalckx, 2001; Vila et al., 2006; Das and Sengupta, 2009). Moreover, there is very limited research regarding the nearshoring practice (Bock, 2008; Iakovou et al., 2010a, b). Finally, a plethora of research papers deal with demand variability by taking into account safety and/or stock-out inventory decisions, i.e. tactical decisions, in conjunction with facility location decisions for a logistics network (e.g. Miranda and Garrido, 2004; Shen and Qi, 2007; You and Grossmann, 2008).

Cargo handling and clearance procedures at ports, customs, and cross-border terminals are regulated at a macro-level by governmental regulations. Most of the related regulatory interventions are in the form of internationally developed tools, recommendations and legislative instruments, occasionally supported by reports, position papers, commentaries, and reference material (Grainger, 2007). On an academic level, only a few research efforts on trade facilitation have been published focusing on different areas such as: (i) the employment of trade facilitation as a trade policy (e.g. Messerlin and Zarrouk, 2000), (ii) the quantitative assessment of the benefits of trade facilitation (e.g. Wilson et al., 2005), (iii) the impact of trade facilitation on customs procedures (e.g. Arvis et al., 2007a, 2010), and (iv) the impact of trade facilitation on supply chain network design (Iakovou et al., 2010a, b). Stalk (2009) discusses convincingly that port congestion and the hidden costs of delays are of extreme concern to companies; he further describes the counter measures that should be taken by global companies to protect themselves against the relevant risks.

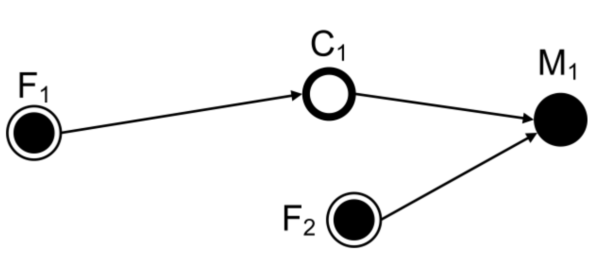
The World Bank (Arvis et al., 2007a) along with expert opinion quantified extensively a large number of indicators regarding domestic logistics environment and supply chain performance and ranked the efficiency and responsiveness of a country's national logistics system through the development of the "Logistics Performance Index", LPI. The LPI of a country is scaled between 1-5 and is based on its: (i) customs clearance process efficiency, (ii) logistics infrastructure, (iii) ability to handle international shipments, (iv) local logistics industry competence, (v) ability to track and trace international shipments, (vi) domestic logistics costs, and (vii) timeliness of shipments in reaching destination. The World Bank updated these indexes for the first time just recently (Arvis et al., 2010).

Finally, regarding supply chain security and strategic emergency stock issues, Sheffi (2001) identifies the basic supply chain disruption modes: disruptions in supply, transportation, at facilities, freight breaches, in communications and demand, while Sheffi et al. (2003) discuss the importance of dual sourcing that differentiates regular business uncertainties from the risks associated with disruptions, using safety stocks to absorb normal business fluctuations on a tactical level, and maintaining a strategic emergency stock only for tackling extremely disruptive events.

3. Problem description

We consider a single market that may be served by two factories, one offshored and one nearshored. Figure 1 depicts the supply chain network under study. Specifically, a regional market (M_1) located for example within the European Union (EU), is served from one offshore factory (F_1) located in Asia and one nearshore factory (F_2) located within the EU. To access the market M_1, containerised cargo originating from the offshore factory F_1 will have to pass through the entry point with customs C_1 using intermodal network.

Figure 1. Supply chain network under study



Using the logistics network of Figure 1, we explore progressively in three phases the system's behaviour. Firstly, in phase I, we determine the optimal mixture of production allocation capacity between the offshore and the nearshore production facilities that minimises total cost as comprised by production, transportation, pipeline, and strategic emergency stock holding costs. The system is examined on a strategic time horizon assuming deterministic demand and stochastic lead times; thus, it captures the impact of lead time variability on pipeline and strategic emergency stock holding costs.

Then, in phase II, we conduct various "what-if" analyses in order to explore the sensitivity of the production sourcing mixture to each parameter included in the problem. Thus, we explore the sensitivity of the production sourcing mixture to: (II.1) the offshore factory's production cost, (II.2) the transportation cost, (II.3) the holding cost, (II.4) the demand level, (II.5) the entry point's customs efficiency (LPI), and (II.6) the market's location from the entry point.

Finally, in phase III we investigate the trade-off between the entry point's customs efficiency and the market's location from the entry point in order to retain the same production sourcing mixture. In the next section we investigate the above three phases for the supply chain network under study.

4. Model development

We consider the problem under study assuming that demand D is deterministic. Lead times are comprised of the transportation time, the delays in total transportation caused by the logistics network infrastructure limitations, and the clearance and service times in customs. The lead time necessary for shipping a container from factory F_i to the market is a random variable and is denoted by t_i with cumulative distribution function $G_i(\bullet)$. The appropriate transport modes (vessel and truck) for a segment of each route are predefined.

We assume that all costs are proportional to the volume of products produced or transported. The pipeline inventory cost per container transported depends on the total order lead time. We further allow the charging of holding costs for maintaining strategic emergency stocks. These stocks are used only in case of irregularly high values of the total lead time (due to quality issues and production or supply disruptions).

In phases I and II, the decision variable is the portion of demand satisfied by the nearshore factory F_2, γ, while in phase III, for a specific portion of demand satisfied by the nearshore factory F_2, the decision variable is the location of market M_1 from the entry point with customs C_1, λ_0. In Table 1 we display all the employed nomenclature.

Table 1. Nomenclature

D	Market's Demand [TEU/day]
T	Replenishment period [days]
p_i	Production cost of factory i [• /TEU]
c_i	Transportation cost from factory i to the market [• /TEU]
h_i	Pipeline holding cost for replenishment from factory i [• /TEU/ day]
t_i	Random variable for lead time from factory i
$g_i(\cdot)$	Probability density function of t_i
$G_i(\cdot)$	Cumulative distribution function of t_i
L_i	Mean lead time from factory i to the market [days]
pr_i	Production cost per unit of factory i [• /unit]
u	Number of products within a TEU [units]
λ_i	Travel distance [km]; i=1 for F_1-C_1, i=2 for F_2-M_1, and i=0 for C_1-M_1.
c_v	Cost for transporting TEUs by vessel [• /TEU/km]
c_t	Cost for transporting TEUs by truck [• /TEU/km]
v_v	Vessel's velocity [km/h]
v_t	Truck's velocity [km/h]
$\xi_{im}(\cdot)$	Transport delays due to the importing country's network [days]
$\xi_{ex}(\cdot)$	Transport delays due to the exporting country's network [days]
$\zeta_{im}(\cdot)$	Processing lead time at the importing customs [days]
$\zeta_{ex}(\cdot)$	Processing lead time at the exporting customs [days]
LPI_i	LPI of country i; i=0 for C_1, i=1 for F_1, i=2 for F_2, i=3 for M_1.
$SES(\gamma)$	Strategic emergency stock [TEU]
r	Protection level from strategic emergency stock [%]
γ	Portion of demand satisfied by the nearshored factory F_2 [%]

To our knowledge, the only relevant quantitative works in the literature that include LPIs in designing and operating supply chains are those of Iakovou et al. (2010a, b). Our previous research efforts dealt with green supply chains taking also into account offshoring vs. nearshoring and trade facilitation issues. The proposed model extends the decisions supported and apart from the identification of the optimal sourcing mixture, it allows the determination of the radius in the hinterland within which a global company can penetrate according to the entry point's customs efficiency. In our work, we utilise the Logistics Performance Index to: (i) capture accordingly the service and clearance mean time, in order to calculate the customs' processing lead time ($\zeta_{im}(\cdot)$ and $\zeta_{ex}(\cdot)$), and (ii) adjust the transportation time by expressing the LPI level into equivalent additional days over the net transportation time ($\xi_{im}(\cdot)$ and $\xi_{ex}(\cdot)$). As the total order lead time is comprised of time delays (service and clearance times in customs and transportation delays) and net transportation times, Iakovou et al. (2010a, b) model the impact of lead time on total cost through the strategic emergency stock and the pipeline holding cost. Arvis et al. (2007a) interpret a difference of one unit in the LPI ranking into six additional days for getting imports from the port to a firm's warehouse and three additional days for exports. In this paper, only two of the seven parameters captured by the LPI index are applicable; the first that affects the delays in port entries, and the second that affects delays in transportation. Based on empirical data, we assume that the delays in port entries are responsible for the one third of the total delays captured by the differences in LPI index, while transportation is responsible for another 10%.

In the following paragraph we present the model developed for the problem under investigation.

4.1 Phases I and II: Determination of the optimal sourcing mixture and sensitivity analysis

The expected total cost for the strategic planning horizon of the system under study $E[TC(\gamma)]$ is given in (1).

$$
\begin{aligned}
E\left[TC(\gamma)\right] = & \int_0^\infty \int_0^\infty \left\{\left[p_1+c_1+\left(h_1\cdot t_1\right)\right]\cdot(1-\gamma)\cdot D\cdot T\right\}\cdot g_1\left(t_1\right)\cdot g_2\left(t_2\right)\cdot dt_1\cdot dt_2 + \\
& + \int_0^\infty \int_0^\infty \left\{\left[p_2+c_2+\left(h_2\cdot t_2\right)\right]\cdot\gamma\cdot D\cdot T\right\}\cdot g_1\left(t_1\right)\cdot g_2\left(t_2\right)\cdot dt_1\cdot dt_2 + \\
& + \int_0^\infty \int_0^\infty \left\{\left[(1-\gamma)\cdot h_1+\gamma\cdot h_2\right]\cdot SES(\gamma)\right\}\cdot g_1\left(t_1\right)\cdot g_2\left(t_2\right)\cdot dt_1\cdot dt_2
\end{aligned} \qquad (1)
$$

After algebraic simplifications equation (1) leads to:

$$
\begin{aligned}
E\left[TC(\gamma)\right] = & \left[p_1+c_1+\left(h_1\cdot L_1\right)\right]\cdot(1-\gamma)\cdot D\cdot T+\left[p_2+c_2+\left(h_2\cdot L_2\right)\right]\cdot\gamma\cdot D\cdot T + \\
& + \left[(1-\gamma)\cdot h_1+\gamma\cdot h_2\right]\cdot SES(\gamma)
\end{aligned} \qquad (2)
$$

Where:

$$p_1 = pr_1 \,.\, u \tag{3}$$

$$p_2 = pr_2 \,.\, u \tag{4}$$

$$c_2 = \lambda_1 \,.\, c_v + \lambda_0 \,.\, c_t \tag{5}$$

$$c_2 = \lambda_2 \,.\, c_t \tag{6}$$

$$L_1 = \zeta_{ex}(LPI_1) + \frac{\lambda_1}{v_v} + \zeta_{im}(LPI_0) + \xi_{ex}(LPI_0) + \frac{\lambda_0}{v_t} + \xi_{im}(LPI_3) \tag{7}$$

$$L_2 = \frac{\lambda_2}{v_t} + \xi_{im}(LPI_3) + \xi_{ex}(LPI_2) \tag{8}$$

The optimal γ^* is the value of γ that minimises (2), namely:

$$\gamma^* = arg \min_{0 \le \gamma \le 1} \left\{ E\left[TC(\gamma) \right] \right\} \tag{9}$$

The first and second terms of (2) are the production, transportation and pipeline expected holding costs realised by the offshore and the nearshore factory, respectively. The last term captures the expected holding cost (weighted average of pipeline holding costs) of the strategic emergency stock that is needed over the longer strategic planning horizon in order to hedge against variability of dual sourcing replenishment. The necessary strategic emergency stock for a protection level r is calculated though equation (10), using the methodology for estimating the optimal $SES(\gamma)$ proposed by Vlachos (2010). The protection level r is set as the probability of no disruption (adequate sourcing) during the lead time.

$$-G_1\left(L_1 + SES(\gamma)/D\right) \cdot G_2\left(L_2 + SES(\gamma)/D\right) + G_2\left(L_2 + SES(\gamma)/D + (1-\gamma)\cdot T\right) \cdot G_1\left(L_1 + SES(\gamma)/D\right) + G_1\left(L_1 + SES(\gamma)/D + \gamma \cdot T\right) \cdot G_2\left(L_2 + SES(\gamma)/D\right) = r \tag{10}$$

Equations (3) and (4) estimate the production cost per TEU of the offshore and the nearshore factory, respectively. Equations (5) and (6) estimate the transportation cost per TEU from the offshore and the nearshore factory to the market, respectively. Equations (7) and (8) estimate the mean lead times from the offshore and the nearshore factory to the market, respectively.

4.2 Phase III: Determination of the optimal market's location for retaining the same production sourcing mixture

The expected total cost for the strategic planning horizon of the system under study $E[TC(\lambda_0)]$ is given in (11), by substituting equations (3)-(8) in (2) and setting as decision variable the market's distance from the entry point.

$$E\left[TC(\lambda_0)\right] = \left\{ \left(pr_1 \cdot u + \lambda_1 \cdot c_v + \lambda_0 \cdot c_t\right) + h_1 \cdot \left[\lambda_1/v_v + \lambda_0/v_t\right] \right\} \cdot (1-\gamma) \cdot D \cdot T + \left[\zeta_{ex}(LPI_1) + \zeta_{im}(LPI_0) + \xi_{ex}(LPI_0) + \xi_{im}(LPI_3) \right] \cdot h_1 \cdot (1-\gamma) \cdot D \cdot T + \left\langle pr_2 \cdot u + \lambda_2 \cdot c_t + \left\{ \left[\lambda_2/v_t + \xi_{im}(LPI_3) + \xi_{ex}(LPI_2)\right] \cdot h_2 \right\} \right\rangle \cdot \gamma \cdot D \cdot T + \left[(1-\gamma)\cdot h_1 + \gamma \cdot h_2\right] \cdot SES(\gamma) \tag{11}$$

The optimal λ_0^* is the value of λ_0 that minimises (11), namely:

$$\lambda_0^* = arg \min_{\lambda_0 > 0} \left\{ E\left[TC(\lambda_0) \right] \right\} \tag{12}$$

5. Numerical Analysis

We consider a supply chain for producing and transporting white goods in a regional EU market with a planning horizon of one year. We set the desirable protection level r at 95%. The transportation costs from node to node are estimated based on the transport mode, taking also into account the distance between the nodes and real market prices in the EU. In addition to the traditional inventory-dependent costs that are encapsulated into the holding cost in this case, pipeline holding costs are also dependent on the type of vessels employed (Arvis et al., 2007b). The developed model is general and can be applied for different distributions. We assume that lead times follow the exponential distribution.

Table 2 displays the input data and the model parameters for the problem under study. Transportation data were obtained by Orphee Beinoglou Intl. Forwarders S.A., a 3PL company with headquarters in Thessaloniki, Greece. Furthermore, the distances were calculated to capture realistically a European port of entry and a regional market in Central Europe. Finally, we assume that a Twenty-foot Equivalent Units

Table 2. Data for the problem under study

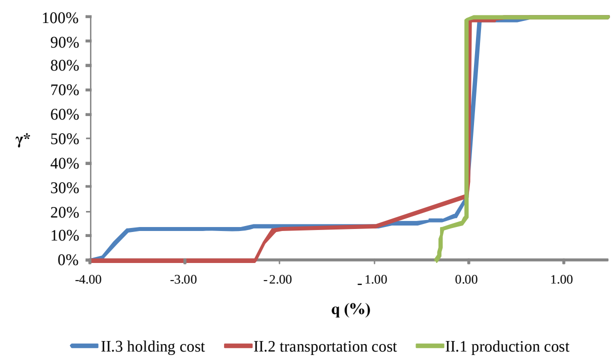
Parameter	Value
pr_1	328 [• /unit]
pr_2	390 [• /unit]
c_v	0.12 [• /TEU/km]
c_t	1.32 [• /TEU/km]
LPI	3.12
λ_1	14066 [km]
h_1	37 [• /TEU/day]
h_2	24.5 [• /TEU/day]
D	13.70 [TEU/day]
T	365 [days]
λ_0	676 [km]
λ_2	835 [km]

container (TEU) contains 40 units of "white" products.

Myopic solutions that take only production, transportation, and pipeline inventory holding costs into account would designate networks with exclusive offshore or nearshore production. However, in this problem the results reveal that the optimal solution assigns production to both factories. More specifically, the optimal mixture of production allocation capacity obtained from (9) proposes 26% of the production to be produced locally. It is worthwhile noting that this dual sourcing is due to the inclusion of the strategic emergency stock in our model.

The sensitivity analyses related to production (II.1), transportation (II.2), and holding costs (II.3) confirmed that an increase of any of these costs may lead to even a 100% nearshore production. On the other hand, for even lower costs than those considered the optimal nearshore allocated capacity could even reach the zero level. Specifically, Figure 2 exhibits the optimal values of γ for various levels of change of each of the costs. To that effect, the horizontal axis of the graph lists the percentage variation of each cost, q; therefore, the resulting new costs would be $p_i' = (1+q).p_i$, $c_i' = (1+q).c_i$, and $h_i' = (1+q).h_i$ for the production, transportation, and holding costs, respectively. The three resulting curves correspond to the II.1, II.2, and II.3 sensitivity analyses with exponential lead times. We observe

Figure 2. Optimal mixtures for using different cost values



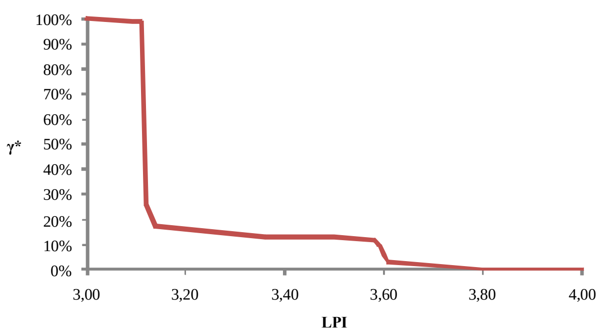
that a small change in each of the costs (even of a 1%) affects significantly the optimal γ. In cases that such a change occurs, the supply chain will have to operate with exclusive offshoring or nearshoring production in order to operate optimally, if the needed capacity is available. Otherwise, the supply chain will retain the production mixture operating with a sub-optimal cost. This result holds for problem instances where the total cost for exclusive offshoring and the total cost for exclusive nearshoring are almost similar.

The sensitivity analysis related to the demand level (II.4) showed that the optimal mixture is constant and independent of the demand level. On the other hand the strategic emergency stock level increases linearly to the demand level.

The results provided by the sensitivity analysis of the optimal mixture to the entry point's customs efficiency (II.5) depict that as the customs' efficiency improves the need for nearshoring production decreases. As Figure 3 exhibits, low LPI's may lead to even a 100% nearshore production, while very efficient and responsive customs may need no replenishment from the nearshore factory.

In the case of the variable market's location from the entry point (II.6), Figure 4 exhibits the results of the sensitivity analysis. When the market is located far away from the entry point, leading to increased transportation costs and lead times, the optimal solution may lead to even a 100% nearshore production. On the other hand, for lower distances than that considered the optimal nearshore allocated capacity could even reach the zero level.

Figure 3. Optimal mixtures for using different LPIs



Finally, for different entry point's customs efficiencies with LPIs ranging from 3 to 5 units and for the mixture of production allocation capacity set equal to 26% we estimate from (11) the optimal market's location for each LPI. Figure 5 depicts the additional travel distance allowed by LPI's improvement in order to retain the same γ^*. The results indicate that an improvement of one tenth of a unit in a country's LPI provides a global company with the opportunity to penetrate markets located about six (6) additional kilometers further in the hinterland.

Figure 4. Optimal mixtures for different market's locations

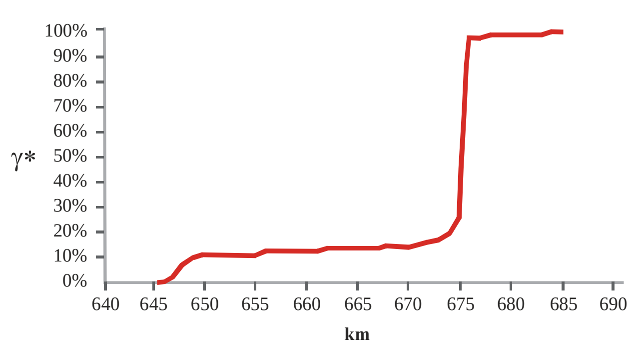
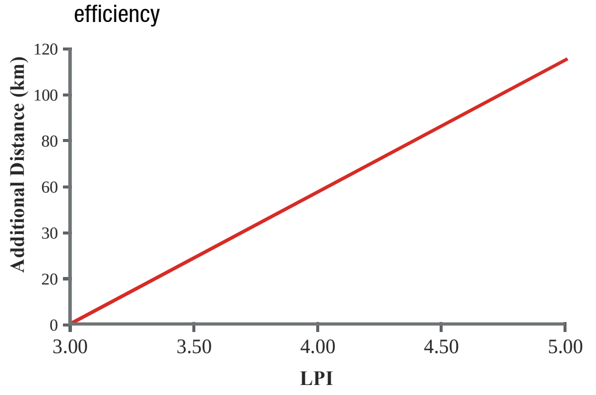


Figure 5. Trade–off between market's location and customs' efficiency



Performing the above calculations setting each time different percentages to the production sourcing mixture, the results reveal that the trade-off between the market's location and the customs' efficiency is the same and thus independent of the mixture of production allocation capacity.

6. Conclusions

Offshoring has led to the relocation of manufacturing plants to BRIC and developing countries. However, free-trade bottlenecks can erode the effectiveness of this policy, thus leading to the nearshoring of a portion of the production processes. In this work, we present a strategic decision methodological framework for the strategic design of global supply chain networks that identifies the optimal mixture of offshoring/ nearshoring policy and the radius in the hinterland within which a global company can penetrate markets according to the entry point's customs efficiency, while capturing quantitatively the impact of trade facilitation related variability.

We demonstrated the application of the proposed methodology on an appropriately simplified problem instance and documented that: (i) holding costs affect the optimal mixture of nearshore/offshore production allocation capacity, (ii) customs characterised by high efficiency and responsiveness are key drivers in the design of globalised supply chain networks as offshore allocation emerges more attractive, and (iii) an improvement in a country's LPI can make its ports more attractive for global supply chain networks as these chains could use those ports as entry points for satisfying additional demand points further located within the related hinterland.

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