Transportation and the Geographical and Functional Integration of Global Production Networks

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Abstract

The growing interest in the relationships between transportation and globalization has spurred many inquiries in the nature of production, consumption and distribution, especially within transport geography. It is widely acknowledged that improvements in transport and distribution have contributed to significant changes in the geographies of production (and vice versa). In a context of intense global competition and diminishing profit margins, logistics and the formation of global production networks offer additional opportunities to improve the efficiency of production through distribution strategies. The spatial and functional fragmentation of manufacturing and attempts at reducing inventories have led to smaller, more frequent and synchronized shipments, transforming the logistics industry, but placing intense pressures on transport systems to support these flows. The benefits derived from global production networks thus cannot be achieved without improvements in logistics and supply chain management. This paper seeks to assess the conditions driving the global forms of production, distribution and transport mainly by looking at the levels of geographical and functional integration of global production networks in view of the high level of fragmentation observed within them. However, there still many uncertainties and delays in distribution, which can only be compensated by a better organization of freight distribution systems supporting global production networks.

Keywords: Global Production Networks, Freight Distribution, Transport Geography, Logistics.

1. Global Production Networks: Synopsis and Paradigms

The growing interest in the relationships between transportation and globalization has spurred many inquiries in the nature of production, consumption and distribution, especially within transport geography. It is widely acknowledged that improvements in transport and distribution have contributed to significant changes in the geographies of production (and vice versa) (e.g. Janelle and Beuthe, 1997; Preston, 2001). In a context of intense global competition and diminishing profit margins, logistics and the formation of global production networks offer additional opportunities to improve the efficiency of production through distribution strategies. In this context, Global Production Networks (GPNs) are accounting for an emerging and active branch of investigation of the various paradigms of globalization (Dicken, 2003; Henderson et al, 2002; Sturgeon, 2001). While the term globalization implies many issues depending on the perspective considered, economic interdependencies in trade,
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production and consumption – core elements of GPNs – are a major factor accounting for its dynamics. The term GPN term itself is revealing as it jointly express the locational, value generation, transactional and distribution reality of the global economy.

It is important to keep in mind that GPNs are bound to the interactions of supply and demand, as they reconcile the material needs of the consumers (let it be an individual or a corporation) to have the right product, in the right quantity, at the right price, at the right location and at the right time, and the capacity of production and distribution systems to accommodate such needs. The embeddedness they reflect is thus multidimensional, as production, distribution and markets become more linked in a complex web of flows (Coe et al, 2004). The development of GPNs has lead to a substantial growth in the flows of commodities, parts and finished goods, hinting at mobility requirements for freight that must be accommodated. In such a context, global freight transport systems have faced additional demands in absolute terms, but also in terms of the average distance goods are carried over. By keeping the quantity transported constant, but increasing its distance, an additional transport demand is implied, literally through a multiplying effect as more distributional capacity gets tied with the same quantity of physical flows. Globalization is thus placing intense pressures on freight transport systems.

In spite of fairly strong evidence, the role of transportation in the emergence of global production networks appears to have been overlooked. GPNs have mainly been considered as an economic phenomenon namely in terms of locational and wealth generation perspectives for the regions at the forefront of globalization. GPNs, within economic geography, have received attention as a space of locations. Although, the importance of distribution is acknowledged, it is assumed that since transportation is a derived demand, its dynamics are simply the outcome of a range of activities taking places along the supply chain. GPNs, seen through the lenses of transport geography, also reveal a space of flows.

The increasing reliance on logistics is changing this conventional perspective about freight transport demand, implying that transportation is more closely integrated to supply chains than previously accounted (Hesse and Rodrigue, 2004; Rodrigue, 2006).

The geography of distribution opens a wider perspective for understanding current changes in the geography of production and consumption. This paper will try to provide additional evidence on how transportation supports and shapes GPNs. It is argued that the relationships between transportation and GPNs are shaped by the paradigms of geographical and functional integration (Figure 1). They particularly maintain the cohesion of GPNs in view of prevalent fragmentation forces at play in the global economy, notably the extended geographical range of operation and the diversity of actors along commodity chains. This attempt goes on par with the growing interests in investigating logistics as a fundamental support of the flows of globalization (e.g. Bowen and Leinbach, 2004; Notteboom, 2004).
GPNs are at start engines of efficiency and productivity that have often expanded from existing production systems that were more regionally or nationally based. Their rationale remains relatively simple, as are economic fundamentals; growth from which additional value (rent) is generated (Figure 1). Since it is impossible to see a uniform allocation of value generation, locations, regions and nations compete for their role within GPNs to derive as much wealth as possible. In this regard, Coe et al. (2004) have identified three forces of regional development, which are value creation, enhancement and capture. Although these forces explain what value generation is, they do not necessarily explain how this process is taking place. This is where the paradigms of functional and geographical integration come into play as they articulate value generation within a geographical setting. The outcomes for commodity chains are twofold:

- **Optimal market potential.** This is mainly a move upward commodity chains to insure that customers’ needs are answered and that additional markets can be serviced. It can take many forms such as the development of new markets, improved products or more efficient and timely retail distribution. Such a strategy is underlined by the growth of global retailing and marketing, where many products, especially technical goods and apparels, have an international reach and recognition (e.g. Gereffi, 1999).

- **Optimal production costs.** This is mainly a move downward the commodity chain to achieve the lowest production cost possible in view of global differences in comparative advantages. Many strategies are possible, namely a move of labor intensive components of the commodity chain to low production costs locations. More recently, activities of growing technical complexity have also been relocated, including several ranges of services. They are accompanied with a fragmentation of GPNs through a spatial division of production particularly made possible by foreign direct investments.

It is quite clear that in both outcomes and depending on the type of industry, globalization has been a dominant strategy to insure their realization.
2. Geographical and Functional Integration

A better conceptual balance should be considered between GPNs as a system of locations and GPNs as a system of flows. Both geographical and functional integration seek to explain the dynamics of embeddedness, one as a spatial process (locations) and the other as an organizational process (structure). They address a shortcoming of the GPN theory which seems to have overlooked issues pertaining to freight distribution. This particularly concerns physical and information flows resulting from a growing fragmentation between production and consumption (Figure 2).

![Geographical and Functional Integration Diagram](image)

**Figure 2 Geographical and Functional Integration**

Functional integration aims at linking more efficiently elements of the supply chain, namely to insure that the needs of the customers are closely met by the suppliers in terms of costs, availability and time. A functional complementarity is thus established through a set of *supply / demand relationships* involving physical flows between parts and raw material suppliers (S), manufacturers (M) and distributors (D). Efficiencies, and thus economies, are achieved through the principle of flow. In this flow-based system, demand is synchronized more closely with supply, imposing a reorganization of freight distribution. This causes a paradigm shift in logistics, where freight distribution evolves from inventory-based logistics (“push” logistics) to replenishment-based logistics (“pull” logistics) (Lasserre, 2004).

The focus of supply chain management is shifting from maintaining inventories aimed at approximately satisfying a demand to a comprehensive data collection system insuring, mainly through on-demand transport, that supply matches more closely with demand. Thus, physical flows are also correlated with significant information flows. This trend is accelerated by the use of logistics, namely a better integration between transport modes and inventory control. Of particular relevance to the logistics industry has been the emergence of
major coordinators and integrators (third and fourth-party logistics providers\(^1\)) that focus on improving a part of the supply chain, especially those under their direct control. While push logistics involves a limited level of integration between suppliers, manufacturers and distributors, a pull logistics system tries to achieve a higher level of efficiency through integration. A process of disintermediation has also taken place where entities within the supply chain are able to bypass traditional intermediaries such as wholesalers and retailers (e.g. Ritchie and Brindley, 2000). Freight flows between components of the supply chain tend to be more frequent and in smaller batches. In addition, the sharing of demand dependant data (such as sales) helps better synchronize supply with demand. Reverse logistics\(^2\) also tends to be better integrated in the system to achieve a higher level of customer service as well as to promote environmental strategies such as recycling.

Geographical integration aims at using the comparative advantages of space, namely to insure a better access to markets, labor, parts and resources. A spatial complementarity is established through a set of origin / destination relationships between the actors of a commodity chain (\(S, M\) and \(D\); Figure 2). Economies are achieved through the principle of location where each actor seeks to find cost and/or income effective locations. Thus, in a conventional situation production systems tended to have a regionally oriented location of its components (1) and finished goods could be exported. With geographical integration, spatially fragmented commodity chains can emerge, where each element can undertake a locational choice to maximize efficiency (implying the use of locations 2, 3 and 4). The function of distribution may also be expanded to cope with this geographical specialization, with the complexity of physical flows, namely in terms of a growth in tons-km.

The strategies of geographical and functional integration tend to be jointly applied, since they are mutually interdependent. What is achieved is an increased level of geographical integration with at least a similar level of functional integration.

3. GPNs, Freight Distribution and Uncertainty

The concepts of functional and geographical integration that have been introduced help articulate GPNs as a system of locations and flows. The resulting freight distribution system is functionally and geographically integrated, but several costs must be assumed to support its underlying fragmentation. They include basic energy expenses to support mobility (flows and transshipments), organizational costs to manage complexity and a variety of infrastructure provision and maintenance costs. As long as those additional costs are compensated by additional benefits, geographical and functional integration can go unabated.

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\(^1\) A third-party logistics provider is an asset based company that offers logistics and supply chain management services to its customers. It commonly owns distribution centers and transport modes. A fourth-party logistics provider integrates the resources of producers, retailers and third-party logistics providers in view to build a system-wide improvement in supply chain management. They are non-asset based meaning that they mainly provide organizational expertise.

\(^2\) Reverse logistics (or reverse distribution) is concerned about the movements of previously shipped goods from customers back to manufacturers or distribution centers due to repairs, recycling or returns.
since they result in additional system-wise value generation. Still uncertainties and delays are prevalent in freight distribution, which may hint at its potential limits.

At start, systems, such as freight distribution, have level of disorder (fragmentation), implying that the higher the level of disorder the more significant the efforts made to maintain its operational conditions. A tendency shared by many systems is to move from order to disorder as they grow in complexity, a process which can be reversed by efficient management. The functional and geographical integration of freight distribution are thus strategies to cope with uncertainties derived from spatial and organizational fragmentation. In such a setting, the state of a freight distribution system is the confidence interval that distribution will occur within an expected time-frame and at an expected cost. Thus, the higher the uncertainty, the less reliable and the more costly freight distribution is. Among the most common sources of uncertainty are capacity constraints, congestion and energy prices, which affect indiscriminately freight distribution. However, functional and geographical integration add their own uncertainties to GPN, one through a more complex supply chain and the other through the impacts of spatial expansion.

Figure 3 Potential Uncertainty Effects of more Complex Supply Chains

The first uncertainty effect in freight distribution concerns the complexity of supply chains where additional production, distribution and consumption actors are incorporated in the GPN. To illustrate the point, a simple distribution system (example A) composed of two producers, a distributor and three consumers can be considered. $T$ is expressing a distribution cost / time function reflecting the importance of cost and time factors for this freight distribution system. Such a function can vary according to the type of products being considered, with some being more cost sensitive while others are more time sensitive\(^3\).

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\(^3\) Time and costs could be considered separately, adding a third axis on the graph, but for the sake of simplicity, they are considered jointly as a cost / time function.
Contemporary GPN tend to have a greater reliance on time issues than before, mainly because of the changes brought by logistics and lower inventory levels (Sommar and Woxenius, 2005). \( p(T) \) is the probability of a specific cost / time event and is assumed to take the shape of a normal distribution. The uncertainty can simplistically be estimated as being the standard deviation of the cost / time function \( T \), as the smaller it is, the more reliable freight distribution is. The surface below the curve is the cost / time performance of this freight distribution system. In such a system, the minimum (physically possible) distribution cost / time function would be \( T^0 \), while the most common distribution cost / time function (highest probability \( p(T^a) \)) would be \( T^a \). Since the system is simple, the standard deviation is small, implying that actors have a reasonable level of confidence that flows would take place within a specific and narrow cost / time range. In this context, freight distribution thus has a low level of uncertainty.

With functional integration, the supply chain becomes more complex (example B), which should in theory make the predictability of flows more difficult since they imply a larger number of actors and intermediaries. Two shifts are involved in such a context. One concerns an increase in the average cost / time of distribution with the minimum cost / time function shifting to \( T^0 \). The second concerns the flattening of the probability distribution where the average time / cost function shifts to \( T^a \). More importantly, the standard deviation increases with a decline of the reliability of distribution and a lower level of performance. The system thus has in theory a higher level of uncertainty in freight distribution.

The second uncertainty effect is the outcome of geography, more specifically of geographical fragmentation using the comparative advantages of various locations. Figure 4 replicates the previous example, but this time considering the theoretical impacts of a growth in the geographical fragmentation of a supply chain on time / costs and reliability. In a relatively compact system (example A), the short distributional distances are favoring a low level of uncertainty as it is logical to assume that smaller distances are linked with timelier freight transport services. In a distribution system operating on an extended geography (such as in a global economy), which can also include another country (example B), uncertainty is higher due to longer distributional distances. For the sake of simplicity, similar shifts in minimum cost / time and in the distribution of probability are assumed. Differential shifts from the respective effects of the complexity of supply chains and geographical fragmentation are expected, most of which would be dependent on the nature of GPN being considered. In this regard, different commodity chains have different levels of tolerance to distributional costs and times.
The uncertainty effects of functional and geographical integration are theoretical, as a more complex and geographically fragmented supply chain may indicate a higher level of uncertainty, but empirical evidence clearly indicates otherwise. The reliability of freight distribution has not decreased (more uncertainty), but increased, a fact underlined by numerous investigations on the performance of supply chains (e.g. Beamon, 1999; Kleijnen and Smits, 2003). Globalization and the emergence of GPNs would simply not have taken place otherwise. Uncertainty and delays have been coped with, indicating growing levels of productivity and added value in manufacturing and freight distribution. This obviously questions the concepts that have been explained so far, even their relevance. The issue in such a context is to understand why uncertainty has not increased in spite of logical expectations of the contrary. Isolating the reasons would help explain the main factors really accounting for the value generation of GPN.

Figure 4 Potential Uncertainty Effect of Geographical Fragmentation
Figure 5 Coping with the Uncertainty of Geographical and Functional Fragmentation

Figure 5 helps understand how the combined uncertainty effects of functional and geographical integration have been compensated by the efficiency of freight distribution. Thus, more functionally integrated and spatially fragmented GPNs are possible without significant changes in the time / cost function. In many cases, costs and reliability have been significantly improved. Two factors are mainly responsible for these improvements:

- **Efficient transport systems.** The growing freight transport demand brought by functional and geographical integration has been met with growing capacity and reliability as well as with additional modes and terminals. The global freight distribution system has seen in the last decades a significant accumulation of capital. Containerization alone played a significant role in improving the efficiency of maritime and inland freight distribution. The vast array of additional shipments and transshipments of raw materials, parts and goods, has induced a substantial growth in energy consumption, particularly petroleum. In addition, a higher reliance on trucking and air transport provided the benefit of faster and more flexible freight distribution, but at the expense of higher energy consumption. For instance, the nation which was the most involved in the growing production and circulation of physical goods – China – was the largest contributor to the growth of global petroleum consumption. Thus, additional capacity and mobility have abated the uncertainty effects of functional and geographical integration. As long as energy remained relatively inexpensive, which was the case up to the beginning of the 21st century, it acted as a strong countervailing force to geographical fragmentation.

- **Supply chain management.** The increasing level of control on physical flows has led to improvements in supply chains, namely over physical distribution and materials management. Timely deliveries can be made and lower inventory levels can be maintained, implying that a large share of the inventory is in constant circulation. A multitude of tasks are involved in the planning and operation of supply chains. Surveys underline the growing importance of the

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4 Temporary surges in oil prices took place such as during the first (1973) and second oil shocks (1979), but were fairly short-lived.
management function, namely information systems, in supply chains (FHWA, 2005). Thus, a better control of the flows through supply chain management, abated the uncertainty effects of functional and geographical integration.

The uncertainty effects behind the emergence of GPNs have consequently been overcome by freight distribution, thus underlining the importance of transportation.

4. Some Empirical Evidence

Reorganization of a GPN: Geographical and Functional Integration

National Semiconductors (NSC) is one of the world's leading manufacturers of semiconductors, offering a range of more than 10,000 different products. It particularly focuses on wireless handsets, display and imaging technologies, information infrastructure and information access devices. The chips manufactured by the company are used in a host of electronic systems; four billion are manufactured each year and are shipped to about 3,800 customers worldwide. Since the manufacturing of semiconductors products involves a wide variety of tasks ranging from capital and technology intensive to labor intensive, the industry is taking the form of a global production network to exploit the comparative advantages required for each task (e.g. Chen, 2002). Simplistically, the process involves wafer fabrication, a capital and technical intensive process, assembly and testing or electronic components, a process which is more labor intensive, and finally distribution to the customers. In turn, this implies a complex distribution system that has to be organized and maintained. To improve its logistics, NSC has substantially modified its spatial freight distribution strategy.

Source: various press releases from National Semiconductors and UPS.
In the early 1990s, the distribution system of NSC relied on five regional distribution centers, each servicing a specific regional market in Europe, North America, and Asia (Figure 6). This GPN reflected well the division of labor common in the semiconductor industry. Delivery cycles were between 9 to 21 days with 700 logistics employees interacting with 42 freight forwarders contracting with 15 airlines. Distribution costs accounted for 2.9% of sales. In the late 1990s, the company opted to outsource its global distribution to a third-party logistics provider (FedEx). The distribution system undertook significant restructuring with the establishment of one global distribution center (GDC) in Singapore, close to the assembly and testing sites in Southeast Asia; its main manufacturing cluster. Such a strategy enabled to reduce the delivery cycle to 2-4 days, depending on the destination, with 100 logistics employees interacting with one logistical supplier. Singapore handles about 90% of the global inventory flows of the company. Distribution costs were lowered to 1.2% of sales. In 2001, UPS Logistics inherited the GDC and undertook a reorganization of the distribution system. The GDC can ship up to 4.2 billion chips a year, which implies 12 million inbound chips fulfilling 1,300 daily orders. The order cycle time varies by the region of destination with 2 days for Asia, 2-4 days for North America, and 2-5 days for Europe. One global DC and a reliance of air transportation have created a GPN which is highly functionally (low cycle times) and geographically (global market) integrated, but dominantly relying on low air transport costs. Doing so, NSC reduced the average delivery time by 47% while reducing distribution costs substantially (Bowman, 2001).
Once the distribution strategy was rationalized and made more efficient cost-wise and
time-wise, NSC embarked in a phase of consolidation of its supply chain by concentrating its
activities in its most efficient facilities. Several plants were sold or shut down and a new
assembly and testing plant was opened in Suzhou, China in 2004. Rationalization has gone
further in 2006 with the closing of the Singapore (Toa Payoh) assembly plant and the
consolidation of assembly and testing activities in Melaka and Suzhou. This has the double
advantage of simultaneously reducing distribution costs as well as production costs. The
recent evolution of the GPN of NSC shows a direct effort to cope with entropy, first by
concentrating all final distribution activities at one location (Singapore GDC) and then by
simplifying the supply chain in large facilities in relative proximity to the GDC. The new
GPN thus reflects a semiconductor industry that has attained a phase of maturity, where
innovation is still important but where competition is increasingly cost-dependant.

**Adjusting to Time-Dependent Freight Distribution: Geographical Integration**

The possibility to agglomerate all distribution activities in a GDC is more an exception
than the norm since in such a case distribution would have to depend entirely on air
transportation. The majority of freight distribution systems are compelled to have other
strategies as the freight being carried has a lower value-to-weight ratio and thus goes through
regular (maritime / land) distribution channels. This includes a wide range of industries such
as apparel (Gereffi, 1999), car parts (Dicken, 2003) or furniture (Leslie and Reimer, 1999).
A more complex spatial strategy including a network of freight distribution centers is thus
required. The question remains concerning the number and the location of those distribution
centers, which is a subject that has been thoroughly investigated by logistical sciences (e.g.
Daganzo, 1999).

Depending on the required response time for freight distribution, a territory such as the
United States can be serviced by a different number of distribution centers (DC). For a land
transport response time of 7 days, only one DC would be required, located at the
demographic centroid of the United States, approximately in Northern Illinois (Figure 7). A
response time of 5 days require two DCs, one of the East Coast and the other on the West
Coast. Each would have a market area of about half the continental United States. As the
required response time gets shorter (3 days and next day) the number of DCs increases
exponentially and their market areas decrease accordingly. A same day response time would
require about 26 DCs (not shown on Figure 7).
This perspective thus represents a balance between a level of service (in terms of time) linked with a level of geographical fragmentation and its associated distribution costs. As the number of distribution centers servicing a territory increases, so does the uncertainty of freight distribution.

**Cross-docking Distribution Centers: Functional Integration**

Cross-docking is the consolidation of shipments from multiple sources to realize economies of scale in outbound transportation. It substantially reduces the inventory-holding function of a warehouse while retaining consolidation and shipping functions. This is done by transferring directly inbound shipments to outbound trucks. Cross-docking leans the timely distribution of freight and a better synchronization with the demand. It is particularly linked with the retail sector (often within large retailers), but can also be applied to manufacturing and distribution. Its main advantages reside with the minimization of warehousing and economies of scale in outbound flows (from the distribution center to the customers). With cross-docking the costly inventory function of a distribution center becomes minimal, while the value-added functions of consolidation and shipping are maintained. Inbound flows (from suppliers) are thus directly transferred to outbound flows (to customers) with little, if any, warehousing. Shipments typically spend less than 24 hours in the distribution center, sometimes less than an hour. In a conventional distribution system, goods are stored in a distribution center (or kept in inventory at the supplier) and wait until ordered by a customer. Under such a setting it is difficult to have shipments that are not less than truckload (LTL). With cross-docking, goods are already assigned to a customer. The distribution center receives goods from suppliers, sort them directly to be shipped to a
consolidated batch (often including other orders from other suppliers) to the customers. Since there is for each supplier less shipments, most of them are full truckload (TL). (Figure 8).

Cross-docking can be applied to a number of circumstances (Gue, 2001). For manufacturing, cross-docking can be used to consolidate inbound supplies, which can be prepared to support just-in-time assembly. For distribution, cross-docking can be used to consolidate inbound products from different suppliers which can be delivered when the last inbound shipment is received. For transportation, cross-docking involves the consolidation of shipments from several suppliers (often in LTL batches) in order to achieve economies of scale. For retail, cross-docking concerns receiving products from multiple suppliers and sorting them to outbound shipments to different stores. The world’s biggest retailer, Wal-Mart, delivers about 85% of its merchandises using a cross-docking system. Coupled with other supply chain strategies, cross-docking permitted the global retailer to improve its inventory turnover\(^6\) from 4.1 in 1990 to 7.7 in 2003 (Schonberger, 2005).

Cross-docking DCs are a good example of functional integration, since suppliers and customers are more closely linked, conferring a higher level of flexibility to the freight distribution system. Considering that cross-docking operates on a virtually non-inventory setting, its locational requirements are different from regular inventory carrying DCs (Gumus and Bookbinder, 2004). In addition to standard locational attributes related to the site and its accessibility, a cross-docking DC is particularly dependant on its intermediacy between supply and consumption clusters. Being able to lessen the number of truck journeys

\(^6\) Inventory turnover is the annual cost of goods sold divided by the value of inventory. The higher it is, the higher the efficiency and profitability since fewer inventories are tied up per unit of sale and cash flow is accordingly increased.
while offering a greater level of truck load enabled cross-docking freight distribution systems to offer a significant effect to counter uncertainty.

5. Conclusion

This article has argued that functional and geographical integration are the main forces behind the embeddedness of GPNs, with transportation being a key factor in maintaining and improving the functional and geographical requirements of supply chains. It has also been argued that functional and geographical integration are forces of uncertainty in supply chains, implying that the spatial fragmentation of production, distribution and consumption places acute pressures on freight distribution to maintain its operations. This perspective mainly stems from the habit and expectation that only one trend is possible in logistics and freight distribution, which is continuous and often incremental improvements related to costs and time components.

In the current context of transnational production and consumption, not to forget the long term trend of rising energy prices, is freight distribution being challenged in its premises? Are the substantial logistical advantages that have so far ensued with globalization and supply chain management simply a temporary process? Considering that freight distribution is mainly a physical system of flows requiring large amounts of energy and management, it is surprising to observe that considerations pertaining to the fragility and uncertainty of freight distribution have been fairly neglected. What appears certain is that globalization and global production networks will face very serious challenges in the coming years. This may lead to substantial adjustments in the logistics industry as it gets “chocked” by higher costs, particularly since the whole system is based on cheap oil. Concomitantly, several elements and functions of GPNs will need to adapt to this new environment. Has the current freight distribution system sowed the seeds of its own end, or is it flexible and adaptable enough, as it should be, to cope with a possible energy transition?

References


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