ISSN: 1576-0162

Fragmentation and Complexity: Analyzing Structural Change in the Chicago Regional Economy

Fragmentación y complejidad: análisis del cambio estructural en la economía de la región de Chicago

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Recibido: junio de 2009; aceptado: octubre de 2009

Abstract

In this paper, two dimensions are differentiated within the fragmentation process: a spatial and a functional one. On the one hand, due to fragmentation and industrial relocation, regional and national economies might be losing some internal linkages. This *spatial fragmentation* determines a decrease in the complexity of the production systems. On the other hand, outsourcing, as a form of *functional fragmentation*, increases the density of transactions and linkages within an economy. The overall impact of fragmentation on the complexity of the regional and national economic systems depends on the net effect of these two fragmentation forces. In this paper, the effects of fragmentation on the complexity of the economy of the Chicago region are studied from a set of input-output tables estimated for the period 1978-2014 using Average Propagation Lengths (APLs).

Keywords: Input-Output; Fragmentation; Average Propagation Lengths; Chicago.

Resumen

En este artículo, se diferencian dos dimensiones en el proceso de fragmentación: una dimensión espacial y otra funcional. Por un lado, debido a la fragmentación y a la deslocalización industrial, las economías regionales y nacionales están perdiendo encadenamientos internos. Esta fragmentación espacial determina una reducción de la complejidad de los sistemas productivos. Por otro lado, la externalización, como forma de fragmentación funcional, incrementa la densidad de transacciones y encadenamientos dentro de una economía. El impacto global de la fragmentación sobre la complejidad de los sistemas productivos nacionales y regionales depende del efecto neto de estas dos fuerzas de fragmentación. En este artículo se estudian los efectos de la fragmentación sobre la complejidad de la economía de la región de Chicago a partir de una serie de tablas input-output estimadas para el período 1978-2014, utilizando longitudes medias de propagación (APLs).

Palabras clave: Input-Output; Fragmentación; Longitudes Medias de Propagación; Chicago.

JEL Classification: C67; D57; L23.

1. Introduction

Over the last few decades, the globalization process has brought about profound changes in technology, industrial organization and the spatial division of labor. Whereas the new economic geography tends to focus on core-periphery distinctions, real-world observations seem to point at economies that are dominated by dis-agglomeration. Part of the problem stems from the need to adequately handle production intermediation. That is, the supply and demand for inputs, which are involved in the processing of goods and services that are ultimately delivered to final demand.

To explain the apparent spatial reorganization of production systems in developed economies, Jones and Kierzkowski (1990, 2005) have proposed an alternative to the new economic geography. Their notion of fragmentation highlights how production processes are being split into subsequent phases that are undertaken separately and in different locations. As a result, we observe an increase in the intra-industry trade of intermediate products, with both an interregional and international character. Production systems in developed areas may thus be losing internal linkages but becoming more dependent on the rest of the world.

Whereas the original concept of fragmentation by Jones and Kierzkowski (1990, 2005) focused on the spatial dimension, something similar has taken place in another dimension. That is, large companies have frequently followed outsourcing strategies in order to focus on their core competences and thus gain efficiency. This outsourcing might be interpreted as a form of functional fragmentation and may induce an increase in the density of transactions and linkages within an economy.

The variety of goods and services produced in an economy may thus decline (due to spatial fragmentation) but within the set produced locally, the degree of intermediation might increase (due to functional fragmentation). This accords with the observations that while the volume of interregional and international trade has increased, a higher percentage is accounted for by intra-industry trade.

Combining the spatial and functional aspects, the final impact of fragmentation on the complexity of production systems (in terms of internal linkages) in developed areas emerges as a matter of interest. Opposing forces are at work and whether one is stronger than the other (or vice versa) largely seems to be an empirical issue.

When studying production intermediation, the input-output accounts and techniques constitute a natural and powerful analytical framework. This paper therefore investigates the fragmentation issue in an input-output framework and employs the so-called Average Propagation Lengths (APLs) (Dietzenbacher et al., 2005; Dietzenbacher and Romero, 2007; Dietzenbacher and Temurshoev, 2008). The empirical part of the paper illustrates the theoretical considerations with the case of the Chicago regional economy, as a representative example of a highly developed area being affected by fragmentation trends (Hewings et al., 1998a, b; Guo et al., 2005).

The remainder of this paper is organized as follows. The next section reviews the recent literature on fragmentation from different points of view. Furthermore, this section aims to develop a more precise conceptual framework for fragmentation. In the third section, some methodological considerations are presented in order to study fragmentation and complexity in an input-output framework and the Average Propagations Lengths (APLs) are introduced. The fourth section studies the effects of fragmentation on the complexity of Chicago's production system by means of APLs. The article concludes with some final considerations.

2. Fragmentation: Conceptual Considerations and Literature Review

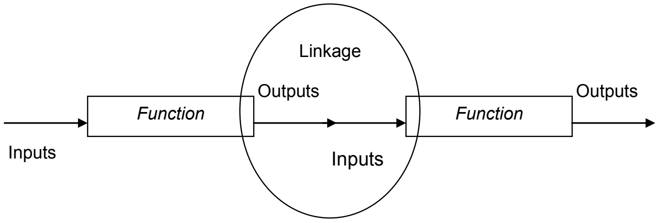
Whereas the original idea of fragmentation in Jones and Kierzkowski (1990, 2005) was more restrictive, we adopt an extended framework for fragmentation in this paper. Following Curzon (2001) or Ruane and Görg (2001), fragmentation will be considered from both the spatial and the functional perspective.[1] From a functional/organizational perspective, production processes can be viewed as a set of linked functions involving the transformation of a set of inputs (such as labor, capital, raw materials, energy, intermediate products) into a set of outputs (see Figure 1).

Furthermore, firms and their establishments can also be viewed as a set of functions linked by internalized transactions. The inputs that firms or establishments require for their production processes may be bought in the market or the provision of inputs can be internalized (which is so-called backward vertical integration). In the same way, firms or establishments can choose between selling their outputs in the market or use them as (internal) inputs to produce a more elaborated output (which is so-called forward

[1] Defever (2006) has previously used the expression 'functional fragmentation' when studying the location patterns of different functions in an MNE. For example, headquarters, R&D, production, logistic and sales and marketing were viewed as the main functions. It should be noted that this paper attaches a different meaning to 'functional fragmentation'.

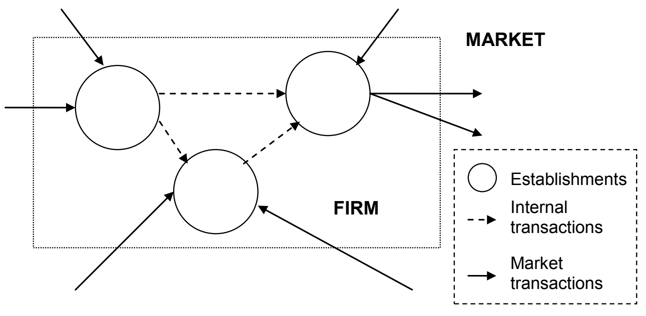
vertical integration).[2] From this perspective, decisions by large companies to disintegrate or externalize certain functions could induce fragmentation. This happens, for example, when functions that were previously carried out within a single establishment are later undertaken in different establishments, being separated by transactions in the market.

Figure 1: Production Chains, Functions and Linkages



The last few decades have witnessed several important changes in technology and industrial organization that have boosted this functional fragmentation. In the 1950s and 1960s, large companies were associated with industrialization and development, whereas small and medium sized enterprises (SMEs) were even considered as a sort of distortion of the development process, as the remains of the early stages in economic evolution. Thus, the model of a large, vertically integrated (say, 'Fordist') company seemed to be the final result of the industrial evolution. In the 1970s, however, these perceptions changed dramatically with the arrival of the economic crisis.

Figure 2: Internal Transactions and Limits of the Firm



[2] Firms or establishments basically take the decisions regarding vertical (dis)integration according to two types of considerations. First, by comparing their cost structure of the functions with the rest of the firms operating in the market. This is the technological view of Stigler (1951). Second, by comparing the transaction costs when using the market with the internal transaction cost of supervision and coordination of functions internally. This is the transactional view of Coase (1937) and Williamson (1975).

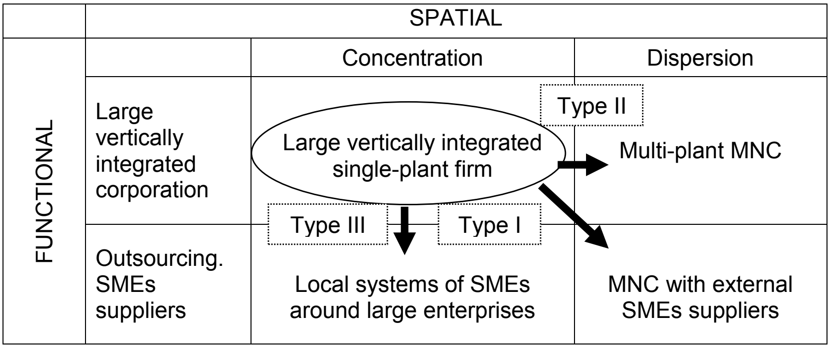
On the one hand, many authors in this period pointed out the comparative advantages of SMEs in terms of flexibility and adaptation capacity to an unstable, changeable and very competitive environment (Piore and Sabel, 1984; Giaoutzi et al., 1988). The crisis of the 'Fordist' corporation was interpreted as the beginning of a new era characterized by the SMEs dynamism. On the other hand, however, other authors considered the changes in large corporations as the evolution towards a new model of a large corporation that Harrison (1994) called 'concentration without centralization.'

Large multinational corporations (MNCs) have frequently concentrated on the functions in which they have their main comparative/competitive advantages and subcontracted other functions in their value chains to SMEs. By means of this outsourcing strategy, large corporations are able to combine two types of advantages. First, advantages from scale and scope economies in the functions which are strategic for them and, second, advantages from flexibility obtained by decentralizing some non-primary functions. This transformation in industrial organization constitutes a vigorous process of *functional fragmentation*.

On the other hand, *spatial fragmentation* implies that production processes are split up in blocks of functions carried out separately. This phenomenon mainly occurs in production processes that have a certain technological complexity. Subsequent functions are organized in blocks that do not need to be performed in the same location or even in the proximity of one another. Each block of functions can thus be undertaken in the best possible location (Arndt and Kierzkowski, 2001). The resulting production blocks are connected through services links, such as transportation, insurance, telecommunications, management coordination, and quality control.

In this respect, globalization is bringing about a re-definition of the spatial division of labor which is altering the geography of production across the world. This process is mainly driven by two factors: international liberalization policies and advances in transportation and telecommunications technologies. The first factor has reduced the cost of tariffs, the obstacles for foreign investments and (specifically due to the domestic deregulation in services) the cost of linking the blocks of functions in fragmented production. The second factor has decreased the transportation costs and the cost of coordination and supervision of activities within large MNCs. As a result, MNCs are currently reconsidering where to locate their plants. Attention is being paid to characteristics of the regions and/or countries such as the cost of production factors, the size of the internal market or institutional and regulatory issues. The reduction of the cost of locating abroad due to globalization prompts them to relocate some plants from highly developed areas to developing countries where production costs are lower.

Figure 3: Fragmentation Framework



Thus, territories are redefining their comparative advantages at a global level, inducing a significant transformation of the interregional and international division of labor. The concept of fragmentation that emerged referred to these ongoing changes in international division of labor and international trade. In this respect, while the international division of labor and specialization has traditionally been considered in terms of final goods, the focus has recently moved to the role of intra-industry trade of intermediate products (Arndt and Kierzkowski, 2001).

In this respect, Hummels et al. (1998, 2001) have proposed the concept of vertical specialization of trade, with different stages of production being undertaken in different countries.[3] Within the fragmentation literature, some authors have considered the implications of this fragmented production for the international intra-industry trade of intermediate components (Chen et al., 2005). Others have drawn attention to the important role of services in fragmentation (Long et al. 2005), the consequences for the wages (Geishecker and Görg, 2005), on the implications for strategic trade policies (Lee and Wong, 2005), among other issues.

Both types of fragmentation (i.e. functional and spatial) may occur simultaneously, for example, when an MNC decides to outsource some functions and contracts SME suppliers located abroad (see Figure 3). In this case, a large company –which often specializes in certain knowledge intensive functions such as design, R&D and marketing– externalizes certain functions related to physical production to other firms in different countries, while it

[3] For Hummels et ál. (2001), vertical specialization exists when: (i) a good is produced in two or more sequential stages, (ii) two or more countries provide value-added during the production of the good, and (iii) at least one country must use imported inputs in its stage of the production process, and some of the resulting output must be exported.

retains the coordination of the whole value chain. (Nike is a clear example of this case.) This form of fragmentation (i.e. both functional and spatial) will be referred to as Type I.

Also spatial fragmentation without functional fragmentation and functional fragmentation without spatial fragmentation are possible. The first type takes place when a vertically-integrated MNC relocates one of its plants to a different place. However, the block of relocated functions remains within the organizational boundaries of the MNC. This form of spatial fragmentation is indicated in Figure 3 as Type II. The latter type (i.e. functional fragmentation without spatial fragmentation) takes place when, for instance, a large firm engages in outsourcing, but operates with SME suppliers within the same territory. This form of functional fragmentation is indicated as Type III.[4]

3. Approaching Fragmentation and Complexity in an Input-Output Framework by Means of APLs

3.1. General Considerations and Main Hypothesis

The effects of fragmentation on the complexity of production systems by fragmentation can be analyzed from the perspective of the input-output model. However, in so doing, two relevant facts need to be taken into consideration. First, the absence of suitable international input-output tables makes it difficult to capture inter-regional and inter-national linkages.[5] Consequently, the increase in the complexity of the world production system due to new and larger international linkages can not be directly measured. Only the internal changes in national and regional production systems due to fragmentation can be observed from available national and regional standard input-output tables.

Secondly, when working in an input-output framework, the relevant unit of analysis is no longer the firm or the establishment, but the sector (or industry). Hence, inter-firm linkages are not the focus of the analysis, but inter-

[4] From a microeconomic perspective, the Global Commodity Chains (GCC) and Global Value Chain (GVC) approaches (see e.g. Gereffi and Korzeniewicz, 1994; Gereffi, 1999; or Humphrey and Schmitz, 2002) address the issue of spatial fragmentation under different patterns of functional fragmentation. In this research stream, firm or industry typologies are developed in order to explain the organization and performance of the different agents (i.e. MNEs, SMEs) participating in GVC.

[5] Inter-country (i.e. inter-regional where countries are the regions) input-output tables have been rarely constructed. The tables for a set of European countries that have been constructed by researchers from the University of Groningen are an exception (see e.g. van der Linden and Oosterhaven, 1995; van der Linden, 1999; or Hoen, 2002; the tables are available at http://www.regroningen.nl). It should be mentioned that the EU-funded project WIOD aims at constructing a series of annual inter-country input-output tables (in current and constant prices) for 40 countries in the world (see http://www.wiod.org).

sectoral linkages. Nevertheless, the three forms of fragmentation: Type I (both spatial and functional fragmentation), Type II (spatial fragmentation without functional fragmentation) and Type III (functional fragmentation without spatial fragmentation) might have effects on the input-output tables in a specific spatial area.

Fragmentation may cause multiple changes in the matrix of intermediate input coefficients. In particular, the diagonal elements are expected to decrease. Moreover, all the direct and indirect changes due to fragmentation will affect the complexity of the whole economic system.

On the one hand, Type III functional fragmentation might increase the complexity of production systems, since new linkages between sectors appear capturing transactions that previously were internalized. In this respect, the process of externalization of some functions by large companies might cause a significant increase in the linkages between industrial and service activities in input-output tables. This phenomenon might also be reinforced by an indirect effect of fragmentation, namely an increased demand for intermediate services. These services (such as telecommunication, transportation, insurance or financial services) link the fragmented production and coordinate activities within the global value chains.

On the other hand, when the impact of spatial fragmentation (included in Types I and II) on the complexity of economic systems is considered, it is necessary to distinguish between two cases. That is, some areas (regions or countries) may lose certain functions, while other areas attract them. From the perspective of areas that lose functions, fragmentation Types I and II might cause a decrease in the complexity of their production systems, since some internal linkages are relocated to outside the area. The consequences of such fragmentation in developed areas might be highly significant, eventually causing a process of hollowing out (Hewings et al., 1998a, b; Guo et al., 2005). As a result of fragmentation, these developed regions might become more dependent on the rest of the world as a source of inputs and as a market for outputs, with the concomitant effect that their intra-regional multipliers will decrease in size.

In contrast, from the perspective of the destination areas, spatial fragmentation might increase the complexity of the economic system. However, it would be necessary that –in addition to fragmentation– some internal linkages with local firms were developed, next to the new international linkages. Thus, in the extreme case of the 'enclave industry' (see e.g. Hardy, 1998, or Romero and Santos, 2007) the assumption of specific functions might not have significant effects on the complexity of the local system in some cases. These enclave industries operate in less developed territories developing specific phases of complex production processes. The intermediate inputs they require are purchased externally and the output is used in subsequent manufacturing activities in plants located in other areas.

Moreover, it is important to view the effects of fragmentation on complexity in a broader perspective, hypothesizing a general pattern of evolution in the complexity of economic systems. According to this idea, complexity would increase parallel to the development process, so that the levels of complexity in highly developed economies are expected to be higher than in less developed economies. This is in line with the ideas and findings of Hirschman (1958), Leontief (1966) or Robinson and Markandya (1973). Nevertheless, as has been argued above, in the current phase of globalization, the complexity of regional and national systems might be decreasing in developed economies due to spatial fragmentation trends. Whether and to what extent this is the case, is a matter of empirical investigation.

3.2. Applying Average Propagation Lengths to Study Fragmentation

Complexity may be defined as the degree of sectoral intermediate production interaction and is measured by the number and size of the internal linkages. In the input-output literature, multiple indicators have been proposed to capture complexity. In fact, any measure for the size of the linkages can be considered as an indicator of the complexity of the system.

When studying the complexity of a production system by means of Average Propagations Lengths (APL, see Dietzenbacher et al., 2005; Dietzenbacher and Romero, 2007; Dietzenbacher and Temurshoev, 2008), the focus of attention has shifted from the size of the effects between sectors to the distance between the sectors. The idea of distance is reflected by the number of steps it takes a stimulus in one sector to affect another sector. It thus yields a measure of the time and cost of adjustment, and, consequently, of the system's complexity.

In general, input-output tables show that (when the total direct and indirect effects are accounted for) each sector sells something to every other sector as well as to itself. Therefore, each sector has a link with every other sector (although many of these links may be small in size). To measure the distance between sectors, the APL can be used. Taking the backward-looking approach, the APL measures for example the average number of steps it takes a final demand increase in hotels and restaurants to propagate throughout the production process and affect the output value in agriculture (see also Sonis et al., 1996). Thus, the APL provides an estimate of the length of the production chains linking any two sectors. In the forward-looking approach, it measures the average number of steps it takes a cost-push in agriculture to affect the output value of hotels and restaurants. As will be shown later, the advantage of APL is that both approaches are equivalent. So, the distance between agriculture and hotels and restaurants does not depend on whether the forward or backward perspective is adopted.

Let z_{ij} (the typical element of the matrix $\mathbf{Z}$) denote the domestic intermediate deliveries (in money terms) from sector i to sector j. The typical element f_i of column vector $\mathbf{f}$ denotes the final demand for the goods and services produced by sector *i*. Final demands include domestic consumption, domestic investments, government expenditures, and gross exports. The typical element w_j of the row vector $\mathbf{w}'$, gives the primary inputs of sector *j*, which include labor costs, capital depreciation, the operating surplus, and imports. The two accounting equations then yield:

$$\mathbf{x} = \mathbf{Ze} + \mathbf{f} \quad (1)$$

$$\mathbf{x}' = \mathbf{e}'\mathbf{Z} + \mathbf{w}' \quad (2)$$

where $\mathbf{x}$ denotes the vector of gross domestic output values in each sector and e is the column summation vector consisting of ones.

From the backward-looking perspective, define input coefficients as $a_{ij} = z_{ij} / x_j$, or in matrix notation as $\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$, where $\hat{\mathbf{x}}$ denotes the diagonal matrix with the elements of the vector $\mathbf{x}$ on its main diagonal. The coefficient a_{ij} indicates the input from sector *i* that is necessary per dollar of output in sector *j*. It also reflects the direct backward linkage or dependence of industry *j* on inputs from industry *i*. Using the input coefficients, accounting equation (1) can be rewritten as:

$$\mathbf{x} = \mathbf{Ax} + \mathbf{f} \quad (3)$$

The solution of this equation yields:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = \mathbf{Lf} \quad (4)$$

where $\mathbf{L} \equiv (\mathbf{I} - \mathbf{A})^{-1}$ denotes the Leontief inverse. If the input coefficients remain the same, an increase $\Delta\mathbf{f}$ in final demands would require that production is increased by $\Delta\mathbf{x} = \mathbf{L}(\Delta\mathbf{f})$ Hence, the typical element l_{ij} provides the (extra) output in sector *i*, that is necessary to satisfy one (extra) dollar of final demand in sector *j*. The power series expansion of the Leontief inverse, i.e. $\mathbf{L} \equiv (\mathbf{I} - \mathbf{A})^{-1} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \ldots$, yields $\Delta\mathbf{x} = \mathbf{L}(\Delta\mathbf{f}) = (\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \ldots)(\Delta\mathbf{f})$. The total increase in the output of sector *i*, due to a final demand increase in sector $j\,(\neq i)$ by one dollar yields

$$\Delta x_i = l_{ij} = a_{ij} + \Sigma_k a_{ik} a_{kj} + \Sigma_k \Sigma_m a_{ik} a_{km} a_{mj} + \ldots \quad (5)$$

The first term on the right hand side expresses the direct effect which requires one step; the other terms are the indirect effects. For example, $a_{ik}a_{kj}$ reflects the two-step indirect effect that runs via industry *k*. That is, the final demand increase in industry *j* will increase the output of industry *k* by a_{kj}, which requires extra inputs from (and thus extra output in) industry *i*. This holds for each industry *k* so that $\Sigma_k a_{ik} a_{kj}$ generates all two-step indirect effects between industries *i* and *j*. In the case *i* = *j*, also the initial effect must be included because the extra final demand must first of all be produced itself. In that case, expression (5) changes into

$$\Delta x_j = l_{jj} = 1 + a_{jj} + \Sigma_k a_{jk} a_{kj} + \Sigma_k \Sigma_m a_{jk} a_{km} a_{mj} + \ldots \quad (6)$$

Thus, the average propagation length (APL) between industries *i* and *j* can now be derived. If the final demand in industry *j* increases by 1 dollar, the output in industry *i* is affected by $\Delta x_i = l_{ij}$. From (5) it follows that the share a_{ij} / l_{ij} requires one step, the share $\Sigma_k a_{ik} a_{kj} / l_{ij}$ two steps, the share $\Sigma_k \Sigma_m a_{ik} a_{km} a_{mj} / l_{ij}$ three steps, etc. The average number of steps it takes the final demand increase in industry *j* to affect the output in industry *i*, thus becomes

$$(1 \times a_{ij} + 2 \times \Sigma_k a_{ik} a_{kj} + 3 \times \Sigma_k \Sigma_m a_{ik} a_{km} a_{mj} + \ldots) / l_{ij} \quad (7)$$

In the case where $i = j$, a similar reasoning applies. Because the initial effect occurs irrespective of the production structure, it does not provide any information on the dependencies and will be neglected. So, a final demand increase by one dollar in industry *j* yields (next to the initial effect) an increase in this industry's output of $\Delta x_j - 1 = l_{jj} - 1$. Using expression (7) gives for the APL

$$(1 \times a_{jj} + 2 \times \Sigma_k a_{jk} a_{kj} + 3 \times \Sigma_k \Sigma_m a_{jk} a_{km} a_{mj} + \ldots) / (l_{jj} - 1) \quad (8)$$

Note that the numerator in expressions (7) and (8) is given by the elements (*i*, *j*) and (*j*, *j*) of the matrix $\mathbf{H} = 1 \times \mathbf{A} + 2 \times \mathbf{A}^2 + 3 \times \mathbf{A}^3 + \ldots = \Sigma_{t=1}^{\infty} t\mathbf{A}^t$ Premultiplying $\mathbf{H}$ by $(\mathbf{I} - \mathbf{A})$ gives $(\mathbf{I} - \mathbf{A})\mathbf{H} = \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \ldots = \mathbf{L} - \mathbf{I}$. Hence $\mathbf{H} = \mathbf{L}(\mathbf{L} - \mathbf{I})$. The APLs are thus obtained as h_{ij} / l_{ij} for $i \neq j$ and as $h_{jj} / (l_{jj} - 1)$.

Next we consider the forward-looking approach. Using the sellers' perspective, output coefficients are defined as $b_{ij} = z_{ij} / x_i$ (or $\mathbf{B} = \hat{\mathbf{x}}^{-1}\mathbf{Z}$), the share of the output of industry *i* that is sold to industry *j*. It reflects the direct forward dependence of industry *i* on sales to industry *j*. Accounting equation (3) can now be rewritten as $\mathbf{x}' = \mathbf{x}'\mathbf{B} + \mathbf{w}'$ and its solution yields $\mathbf{x}' = \mathbf{w}'(\mathbf{I} - \mathbf{B})^{-1} = \mathbf{w}'\mathbf{G}$. This model is well known as the supply-driven input-output model proposed by Ghosh (1958) (see Dietzenbacher, 1997, for a thorough discussion and further literature).

The element g_{ij} of the Ghosh inverse $\mathbf{G} \equiv (\mathbf{I} - \mathbf{B})^{-1}$ reflects the total (or direct plus indirect) dependence of industry *i* on industry *j*. In deriving the APL between industries *i* and $j\ (\neq i)$., consider an increase the primary costs of industry *i* by one dollar. The output value in industry *j* increases by $\Delta x_j = g_{ij} = b_{ij} + \Sigma_k b_{ik} b_{kj} + \Sigma_k \Sigma_m b_{ik} b_{km} b_{mj} + \ldots$. The first term gives the (one-step) direct effect, the second term the two-step indirect effect, the third term the three-step indirect effect, etcetera. The average number of steps it takes a cost-push in industry *i* to affect the output value in industry *j* is thus given by

$$(1 \times b_{ij} + 2 \times \Sigma_k b_{ik} b_{kj} + 3 \times \Sigma_k \Sigma_m b_{ik} b_{km} b_{mj} + \ldots) / g_{ij} \quad (9)$$

The numerator can be written as $\tilde{h}_{ij}$, with $\tilde{\mathbf{H}} = \mathbf{G}(\mathbf{G} - \mathbf{I})$, and the APLs are given by $\tilde{h}_{ij} / g_{ij}$. When $i = j$, the APLs are (similar to backward-looking case) given by $\tilde{h}_{jj} /(g_{jj} - 1)$ when the initial effect is neglected.

Finally, we show that the APLs are the same for the forward and the backward case. From the definition of the input and the output coefficients it follows that $b_{ij} = a_{ij} x_j / x_i$, or $\mathbf{B} = \hat{\mathbf{x}}^{-1}\mathbf{A}\hat{\mathbf{x}}$. As a consequence we have $\mathbf{G} = (\mathbf{I} - \mathbf{B})^{-1} = \hat{\mathbf{x}}^{-1}(\mathbf{I} - \mathbf{A})^{-1}\hat{\mathbf{x}} = \hat{\mathbf{x}}^{-1}\mathbf{L}\hat{\mathbf{x}}$ and also $\mathbf{G} - \mathbf{I} = \hat{\mathbf{x}}^{-1}(\mathbf{L} - \mathbf{I})\hat{\mathbf{x}}$. Therefore $\tilde{\mathbf{H}} = \mathbf{G}(\mathbf{G} - \mathbf{I}) = \hat{\mathbf{x}}^{-1}\mathbf{L}(\mathbf{L} - \mathbf{I})\hat{\mathbf{x}} = \hat{\mathbf{x}}^{-1}\mathbf{H}\hat{\mathbf{x}}$. That is, $\tilde{h}_{ij} = h_{ij} x_j / x_i$ and $g_{ij} = l_{ij} x_j / x_i$. For the APL in the forward case we thus find $\tilde{h}_{ij} / g_{ij} = h_{ij} / l_{ij}$, which is the APL in the backward case.

APLs have a straightforward application for measuring the effects of fragmentation on the complexity of production systems. On the one hand, spatial fragmentation induces relocation of production to other regions (or countries). Production chains that previously were completely undertaken in the home region (or country) are split up and performed in different regions (or countries). Consequently, the complexity and interdependencies of the production system will diminish in the home region. A larger part of the total effects will come from direct effects and APLs will decrease. In contrast to this, in the areas attracting new activities, the complexity of the production system, the size of indirect effects and the length of production chains could increase, provided that some local linkages are developed. On the other hand, functional fragmentation might imply the appearance of new linkages due to the externalization of what previously were internal transactions. These new linkages will eventually have the effect of lengthening production chains and increasing APLs.

4. FRAGMENTATION AND STRUCTURAL CHANGE IN THE CHICAGO REGIONAL ECONOMY

Over the last three decades, the Chicago regional economy has undergone some significant transformations. In the early 1970s, the region was dominated by manufacturing production. In 2009, the structure of the economy has been transformed to look very similar to the US as a whole. This transformation took place as a result of the simultaneous decline in the share of manufacturing production in gross regional product and the parallel increase in service-related production. Notwithstanding this transformation, the region's economy remains somewhat out of phase with the US economy in terms of business cycle behavior (see Hewings, 2008); the reasons may be found in the nature of goods and services produced as well as Chicago's role in national and regional production chains. The analysis of the APLs may provide some important insights into the explanations for the mismatch between Chicago's actual macro economic performance and the expectations that, with a similar economic structure, it should behave in a similar fashion to the national economy.

The annual input-output tables are derived from an econometric input-output model developed for the Chicago region. Base year input-output tables, assembled in large part from establishment level data for 1987 and 1992, were integrated into an econometric model that was solved in a similar fashion to a standard Walrasian general equilibrium model. However, in this case, prices were not adjusted to clear markets but input coefficients; as noted in Israilevich et al. (1997), the system may be considered a general equilibrium model of the Marshallian type. In the version of the model used in this paper, annual input-output tables with 36 sectors identified were extracted from the system for the period 1978 to 2014.

For each 36x36 input-output table, the matrix giving the APL between each pair of sectors was calculated. The element APL_{ij} of that matrix indicates the average propagation length of a cost-push in sector *i* (directed forward) to affect the output value in sector *j*. At the same time, it gives the average propagation length of a demand-pull (directed backward) from sector *j* to *i*. Thus, considering the matrix for the year 2009 as an example, the largest APL is found for the linkage from Lumber and Wood Products to Printing and Publishing (5.71) and the smallest APL is found for self-consumption in the Tobacco industry (1.08).

When considering the distances from one sector to any sector in the production system, we take averages. This may be done from two perspectives, a forward and a backward. The forward average APL is defined as:

$$FA_i = \frac{1}{n}\sum_{j=1}^{n} APL_{ij} \quad (10)$$

and the average backward APL is defined as:

$$BA_j = \frac{1}{n}\sum_{i=1}^{n} APL_{ij} \quad (11)$$

where n is the number of sectors, in the case of the Chicago regional economy $n = 36$.

The forward average APL (FA_i) gives the average distance from sector *i* to any sector *j* when considering the effects on the output value of sector *j* due to a cost-push in sector *i*. Table 1 gives the FAs and BAs in 2009. The largest FA corresponds to Mining (4.48) and the smallest to the Federal Government Enterprises (3.62).

The backward average APL (BA_j) gives the average distance from sector *j* to any sector *i* when considering the effects on the output value in sector *i* due to of a demand-pull from sector *j*. For the estimated input-output table of 2009, Table 1 shows that the largest BA corresponds to the Petroleum sector (4.15) and the smallest to Forestry, Fisheries and Agricultural Services (3.69).

A large FA together with a small BA indicates that a sector is situated at the beginning of production chains. This is, for instance, the case for Livestock, and Agricultural Products in Table1 for 2009 (FA = 4.38; BA = 3.72). A large BA and a small FA indicate that a sector is situated at the end of production chains. An example in the 2009 input-output table might be the Rubber and Plastics sector (BA = 4.14; FA = 3.69).

Finally, the overall average of the APLs can be used as an index for measuring complexity of the production system. That complexity index (*CI*) would be given by the following expression:

$$CI = \frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n} APL_{ij} = \frac{1}{n}\sum_{i=1}^{n} FA_i = \frac{1}{n}\sum_{j=1}^{n} BA_j \quad (12)$$

The complexity index calculated from the 2009 input-output table is 3.90, indicating the average distance between any possible pair of sectors in the 36x36 input-output table.

Table 1: APL Averages

Sector Description	*Sector number*	FA (2009)	BA (2009)	FA. Change (%) 1978-2014	BA. Change (%) 1978-2014
Livestock, Agric. products	1	4.38	3.72	19.1	20.8
Forestry, Fisheries, Agric. Serv.	2	3.99	3.69	19.9	22.2
Mining	3	4.48	3.83	18.6	20.9
Construction	4	3.75	3.79	23.8	21.6
Food and Kindred products	5	4.05	4.04	22.5	22.0
Tobacco	6	3.74	3.77	23.4	21.0
Apparel and Textiles	7	3.80	3.90	23.4	22.4
Lumber and Wood products	8	4.33	3.95	19.6	21.9
Furniture and Fixtures	9	3.82	3.79	22.8	21.6
Paper and Allied products	10	4.09	4.03	16.8	21.0
Printing and Publishing	11	4.03	4.10	22.6	18.0
Chemicals and Allied products	12	3.85	4.13	22.0	22.1
Petroleum	13	3.90	4.15	23.2	20.6
Rubber and Plastics	14	3.69	4.14	19.7	23.1
Leather	15	3.78	3.97	21.7	20.6
Stone, Clay and Glass	16	4.02	3.95	25.6	23.1
Primary Metals	17	4.19	3.83	15.9	20.0
Fabricated Metals	18	4.02	3.84	20.9	21.6
Non Electrical Machinery	19	3.79	3.90	21.8	20.3
Electrical Mach. & Electronic	20	3.88	3.89	19.2	18.5
Transportation Equip.	21	3.72	3.73	21.0	17.3
Instruments	22	3.83	3.84	22.7	20.7

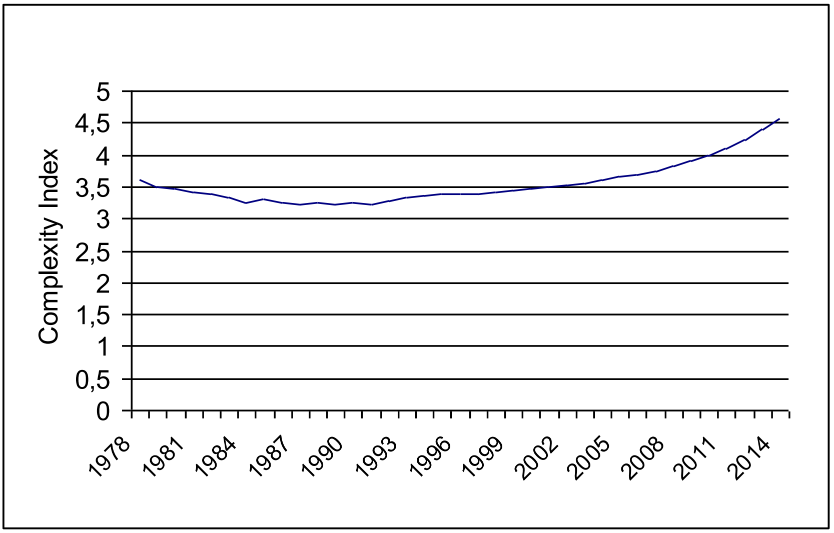
Miscellaneous Manufac.	23	3.64	3.83	17.8	22.4
Transportation	24	3.87	4.04	23.0	22.6
Communications	25	4.00	3.85	22.2	21.6
Utilities	26	3.64	3.89	18.3	15.0
Trade	27	3.70	3.79	22.6	22.7
Finance, Insurance	28	3.76	3.93	23.0	23.6
Real Estate	29	3.75	4.10	21.4	23.0
Hotels, Repair Services	30	3.82	3.82	21.7	22.5
Eating & Drinking Places	31	3.77	3.82	22.7	21.1
Auto Repair & Services	32	3.88	3.91	22.8	20.9
Amusements & Recreation	33	4.20	3.77	18.6	21.1
Health & Nonprofit	34	3.83	3.76	23.5	22.5
Federal Govt. Enterprises	35	3.62	3.82	19.8	22.4
State & Local Gov. Enterpr.	36	3.65	3.95	20.1	19.6
Average (CI)		3.90	3.90	21.2	21.2

The effects of fragmentation can be approached by the changes in these FA, BA and CI. As can be seen in Table 1, both forward and backward average APLs increase for all the sectors in the Chicago regional economy in the period 1978-2014, showing an average growth rate of 21.2%. Regarding the forward averages, the largest growth rate is found for Stone, Clay and Glass (25.6%), whereas the smallest growth rate corresponds to Primary Metals (15.9%). With respect to the backward averages, the largest growth rate is found for Finance and Insurance (23.6%) and the smallest for Utilities (15.0%).

The results show that fragmentation (as measured by the growth rate in the average APLs) is spread over the sectors in a very even way. Whereas it might have been expected that fragmentation affects some sectors much more than other sectors, this does not seem to be the case. The effects of fragmentation are observed throughout the entire system to the same extent.

Figure 4 shows the evolution of the complexity index CI. As can be seen, we can clearly distinguish two different periods in the evolution of the complexity levels of Chicago's production system. In the first period, 1978-1991, CI decreases, indicating a reduction in the complexity of the production structure. The minimum is reached in 1991 with a CI of 3.23. This tendency can be explained as a result of the relocation of productive activity out of the region prompted by fragmentation of Type I (i.e. simultaneous functional and spatial fragmentation due to externalization of certain functions to other firms) and Type II (i.e. spatial fragmentation due relocation of blocks of functions within the firm). In this respect, the Chicago economy has experienced an overall decrease in the level of intermediation. Many parts of the value chain of production either relocated or disappeared altogether (in cases where the production was ceased).

Figure 4: Complexity Trends in the Chicago Regional Economy



However, since 1992 this declining tendency has inverted and the CI systematically increases, indicating higher levels of complexity in Chicago's economic system. This fact might be attributed, among other reasons, to an increment of market linkages due to outsourcing as well as to the impacts of increased specialization within the product mix of each sector. From this perspective, the effect of fragmentation Type III (i.e. functional fragmentation, such as outsourcing, by large firms within the region) might have contributed to neutralize the consequences of fragmentation of Types I and II on the complexity of the Chicago productive system. Thus, the complexity index shows an overall increase of 21.2% in period 1978-2014.

5. Conclusion

In this paper we have analyzed fragmentation in the Chicago regional economy, applying the average propagation lengths. Summarized, the outcomes can be viewed as being generated by a process with three characteristics. (1) The Chicago economy has experienced a process of hollowing out due to spatial fragmentation, causing an overall reduction in intermediation. (2) A decrease in the variety of goods and services produced in any one sector (i.e. secondary product production has decreased). (3) An increase in the specialization of production in each sector. This latter observation is consistent with the NEG ideas of the dominance of scale economies and the ability of an individual establishment to serve more extensive geographic markets.

The spatial fragmentation in (1) has caused a decrease in APLs and in the Complexity Index (CI). The functional fragmentation that brings about the processes in (2) and (3), has led to an increase in the APLs and in the CI. These two forces clearly have opposed effects on the CI, i.e. (1) versus (2) and (3). In the period 1978-1991, the first was dominant, while the second was stronger in the period 1992-2014. The overall result shows (see Figure 4) that the Chicago economy is more complex in 2014 than in 1978. Chicago is producing more but it is more specialized and less dependent on the local economy for inputs (i.e. the direct dependence has decreased). However, the Chicago system is more complex, in the sense that more transactions between firms and sectors are necessary to accommodate a cost-push or a demand-pull (i.e. the indirect dependence has increased).

References

Arndt, S.W. and Kierzkowski, H. (2001): "Introduction", *Fragmentation. New Production Patterns in the World Economy*, Oxford University Press, Oxford, 1-16.

Chen, H. ; Kondratowicz, M. and Yi, K-M. (2005): "Vertical Specialization and Three Facts About U.S. International Trade", *The North American Journal of Economics and Finance*, 16, 35-59.

Coase, R.H. (1937): "The nature of the firm", *Economica*, 4, 386-405.

Curzon, V. (2001): "Some causes and consequences of fragmentation", *Fragmentation. New Production Patterns in the World Economy*, Oxford University Press, Oxford, 88-107.

Defever, F. (2006): "Functional Fragmentation and the Location of Multinational Firms in the Enlarged Europe", *Regional Science and Urban Economics*, 36, 658-677.

Dietzenbacher, E. (1997): "In Vindication of the Ghosh Model: A Reinterpretation as a Price Model", *Journal of Regional Science*, 37, 629-651.

Dietzenbacher, E. and Romero, I. (2007): "Production Chains in an Interregional Framework: Identification by Means of Average Propagations Lengths", *International Regional Science Review*, 30, 362-383.

Dietzenbacher, E.; Romero I. and Bosma, N.S. (2005): "Using Average Propagation Lengths to Identify Production Chains in the Andalusian Economy", *Estudios de Economía Aplicada,* 23, 405-422.

Dietzenbacher, E. and Temurshoev, U. (2008): "Ownership Relations in the Presence of Cross-Shareholding", *Journal of Economics,* 95, 189-212.

Geishecker, I. and Görg, H. (2005): "Do Unskilled Workers Always Lose from Fragmentation", *The North American Journal of Economics and Finance*, 16, 81-92.

Gereffi, G. (1999): "International Trade and Industrial Upgrading in the Apparel Commodity Chain", *Journal of International Economics,* 48, 37-70.

Gereffi, G. and Korzeniewicz, M. (eds.) (1994): *Commodity Chains and Global Capitalism*, Praeger, London.

Giaoutzi, M.; Nijkamp, P. and Storey, D.J. (1988): "Small is Beautiful – The Regional Importance of Small-scale Activities", in Giaoutzi, M.; Nijkamp P. and Storey, D.J. (eds.): *Small and Medium-sized Enterprises and Regional Development*, Routledge, Londres, 1-18.

Ghosh, A. (1958): "Input–output approach in an allocation system", *Economica,* 25, 58-64.

Guo, D.; Hewings, G.J.D. and Sonis, M. (2005): "Integrating Decomposition Approaches for the Analysis of Temporal Changes in Economic Structure: An Application to Chicago's economy from 1980 to 2000", *Economic Systems Research*, 17, 297-315.

Hardy, J. (1998): "Cathedrals in the Desert? Transnationals, Corporate Strategy and Locality in Wroclaw", *Regional Studies,* 32, 639-652.

Harrison, B. (1994): *Lean and Mean. The Changing Landscape of Corporate Power in the Age of Flexibility*. Harper Collins Publishers, New York.

Hewings, G.J.D. (2008): "On Some Conundra in Regional Science", *Annals of Regional Science*, 42, 251-265.

Hewings, G.J.D.; Sonis, M.; Guo, J.; Israilevich, P.R. and Schindler, G.R. (1998a): "The Hollowing-out Process in the Chicago Economy, 1975-2015", *Geographical Analysis*, 30, 217-233.

Hewings, G.J.D.; Israilevich, P.R.; Schindler, G.R. and Sonis, M. (1998b): "Agglomeration, Clustering and Structural Change: Interpreting Changes in the Chicago Regional Economy", in Steiner, M. and Cappellin, R. (eds.): *From Agglomeration Economies to Innovative Clusters,* Pion, London.

Hirschman, A.O. (1958): *The Strategy of Economic Development*, Yale University Press, New Haven.

Hoen, A.R. (2002): *An Input-Output Analysis of European Integration*, North-Holland, Amsterdam.

Hummels, D. ; Rapoport, D. and Yi, K-M. (1998): "Vertical Specialization and the Changing Nature of World Trade", *Economic Policy Review* (Federal Reserve Bank of New York), June, 79-97.

Hummels, D. ; Ishii, J. and Yi, K-M. (2001): "The Nature and Growth of Vertical Specialization in World Trade", *Journal of International Economics*, 54, 75-96.

Humphrey, J. and Schmitz, H. (2002): "How Does Insertion in Global Value Chains Affect Upgrading Industrial Clusters?", *Regional Studies,* 36, 1017-1027.

Israilevich, P.R.; Hewings, G.J.D.; Sonis, M. and Schindler, G.R. (1997): "Forecasting Structural Change With a Regional Econometric Input-output Model", *Journal of Regional Science*, 37, 565-590.

Jones, R.W. and Kierzkowski, H. (1990): "The Role of Services in Production and International Trade: A Theoretical Framework", in Jones, R.W. and Krueger, A.O. (eds.): *The Political Economy of International Trade: Essays in Honor of Robert E. Baldwin*, Basil Blackwell, Oxford.

Jones, R.W. and Kierzkowski, H. (2005): "International Fragmentation and the New Economic Geography", *The North American Journal of Economics and Finance*, 16, 1-10.

Lee, J. and Wong, K. (2005): "Vertical Integration and Strategic Trade Policies", *The North American Journal of Economics and Finance*, 16, 93-117.

Leontief, W. (1966): *Input-Output Economics*. Oxford University Press, New York.

Long, N.V.; Riezman, R. and Soubeyran, A. (2005): "Fragmentation and Services", *The North American Journal of Economics and Finance*, 16, 137-152.

Piore, M.J. and Sabel, C.F. (1984): *The Second Industrial Divide – Possibilities for Prosperity*, Basic Books, New York.

Robinson, S. and Markandya, A. (1973): "Complexity and Adjustment in Input-Output Systems", *Oxford Bulletin of Economics and Statistics*, 35, 119-134.

Romero, I. and Santos, F.J. (2007): "Firm Size and Regional Linkages. A Typology of Manufacturing Establishments in Southern Spain", *Regional Studies,* 41: 571-584.

Ruane, F. and Görg, H. (2001): "Globalization and Fragmentation: Evidence for Electronic Industry in Ireland", in Arndt, S.W. and Kierzkowski, H. (eds.): *Fragmentation. New Production Patterns in the World Economy*, Oxford University Press, Oxford, 144-164.

Sonis, M.; Hewings, G.J.D. and Haddad, E. (1996): "A Typology of Propagation of Changes on the Structure of a Multiregional Eonomic System: The Case of the European Union 1975-1985", *Annals of Regional Science*, 30, 391-408.

Stigler, J.G. (1951): "The Division of Labor is Limited by the Extent of the Market", *Journal of Political Economy*, 59, 185-193.

Van der Linden, J.A. (1999): *Interdependence and Specialisation in the European Union*, PhD thesis, Department of Economics, University of Groningen.

Van der Linden, J.A. and Oosterhaven, J. (1995) European Community Intercountry Input-Output Relations: Construction Method and Main Results for 1965-1985", *Economic Systems Research*, 7, 249-269.

Williamson, O.E. (1975): *Markets and Hierarchies: Analysis and Antitrust Implications. A Study in the Economics of Internal Organization*, Macmillan New York.