Economic Complexity as Input-Output Interrelatedness: A Comparison of Different Measurement Methods

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ABSTRACT:

Economic complexity can be defined as the level of interdependence between the component parts of an economy. In input-output systems intersectoral connectedness is a crucial feature of analysis, and there are many different methods of measuring it. Most of the measures, however, have important drawbacks to be used as a good indicator of economic complexity, which motivated us to propose, in a previous work, a new index of connectedness explicitly for this purpose. In this paper, we compare empirically different indexes, using the inter-industry tables of several OECD countries.

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1. Introduction

Complexity is a multidimensional phenomenon with several approaches and many theoretical definitions. Originated in physical and biological sciences, the notion of complexity has been usefully extended to the analysis of social and economic systems.

In the economic context, one interesting dimension of complexity is the level of interdependence between the component parts of an economy. The Leontief input-output model is, by its very nature, one of the best theoretical and empirical methodologies for studying it.

In fact, inter-sectoral connectedness is the central feature of input-output analysis, and there are, as expected, many different ways of measuring it, from the earlier and simple Chenery and Watanable(1958) and Rasmussen-Hirschman(1958) indicators, to more complicated methods as the Yan and Ames (1963) interrelatedness measure, the dominant eigenvalue measure of Ditzenbacher(1992), the ecological measures of Finn(1981) and Ulanowicz(1983), the complexity as interdependence measure of Amaral, Dias and Lopes(2007), and many others. These measures are presented and briefly discussed in section 2 of the paper.

The main part of the paper (section 3) is a detailed quantification of economic complexity as connectedness, applying the rich menu of (input-output) measures presented and discussed in section 2 and confronting them empirically, using the inter-industry tables of several OECD countries. And section 4 concludes the paper.

2. Measures of Input-Output Connectedness

There are several measures of connectedness in input-output analysis. Although not explicitly made for that purpose, they can be considered as alternative measures of economic complexity as sector interrelatedness. And it is an interesting exercise *per se* to rank the economies according to the level of interrelatedness obtained for each of them.

In this section, we present a (not exhaustive) list of measures, from the traditional ones to some recent and more theoretically elaborated. Most of these measures were proposed by authors in economics but there are also some proposed by biologists, and have an ecological content. A still useful, but relatively old, survey of these measures is Szyrmer(1985). A more recent one is Basu and Johnson(1996).

One of the first indicators of connectedness of an input-output system is the Percentage Intermediate Transactions (M1 – PIT) of Chenery and Watanable(1958), defined as “the percentage of the production of industries in the economy which is used to satisfy needs for intermediate inputs”, and defined as:

$$PIT = 100\frac{i'Ax}{i'x}$$

Another classical measure of connectedness is the Average Output Multipliers" (M2 – AOM) proposed by Rasmussen-Hirschman(1958):

$$AOM = \frac{1}{n}i'(I - A)^{-1}i$$

A similar measure is used by Blin and Murphy(1974), with n^2 in the denominator.

Useful only in very disaggregate matrices is the Percentage of Nonzero Coefficients measure (M3 – PNZC) of Peakock and Dosser (1957):

$$PNZC = \frac{100}{n^2}i'Ki,$$

with K a Boolean matrix, such as: $k = [k_{ij}], k_{ij} = \begin{cases} 1, a_{ij} \neq 0 \\ 0, \text{otherwise} \end{cases}$

A simple but useful measure is the Mean Intermediate Coefficients Total per Sector (M4 – MIPS, Jensen and West, 1980):

$$MIPS = \frac{1}{n}i'Ai$$

Based on the work of Wang(1954) and Lantner(1974) is the idea that the smaller the value of |I-A|, the larger the elements of Leontief inverse and so the interrelatedness of the IO system, and so we can use the Determinant measure (M5 – DET):

$$\mathrm{DET} = \frac{1}{|\mathrm{I} - \mathrm{A}|}$$

A more elaborate one is the Yan and Ames(1963) interrelatedness measure (M6 – YAM), defined as:

$$\mathrm{YAM} = \frac{1}{n^2} \sum_{i,j} \frac{1}{O_{ij}^{YA}}$$

where O_{ij}^{YA} : is the Order Matrix, with each entry representing the smallest order of interrelatedness between i and j, that is, given the series A, A^2, A^3, …, A^k, k consisting of the exponent necessary to convert the corresponding cell to nonzero.

More recently, Dietzenbacher(1992) proposed as an alternative measure of connectedness the Dominant Eigenvalue of Matrix A (M7 – DEA):

$$\mathrm{DEA} = \lambda ,$$

with λ: the dominant eigenvalue of matrix A.

With particular importance for the study of ecological systems are the following measures of connectedness (for a detailed presentation see Szyrmer,1985).

The Mean Path Length (M8 – MPL):

$$MPL = \frac{i'Xi}{i'y},$$

where $i'Xi = t$, is total system output, and i’y is the final demand flow.

The Cycling Index (M9 – CI):

$$CI = \frac{b}{t},$$

where $b = \sum_j (1 - \frac{1}{b_{jj}})x_j$ is the sum of cycling flows.

The Straight-Through Flow Index (M10 – STFI):

$$STFI = \frac{(t-b)}{t},$$

that is, the non-cycling fraction of total through flow (note that better connected systems are those with larger total system flow and longer average flow path).

Another kind of measure, explicitly made for quantifying economic complexity as input-output interdependence is proposed by Amaral, Dias and Lopes(2007), based in Amaral(1999).

This measure considers i) a "network" effect, that gives the extent of direct and indirect connections of each part of the system with the other parts, more connections corresponding to more complexity; and ii) a "dependency" effect, that is, how much of the behavior of each part of the system is determined by internal connections between the elements of that part – which means more autonomy and less dependency – and how much that behaviour is determined by external relations that is, relations with other parts of the system – which means less autonomy and more dependency.

A brief description of this measure is presented here, following closely Amaral *et al* (2007).

Consider a system represented by a square matrix **A**, of order N and with all values non negative. A part of the system of order m (m = 1, …,N-1), is a square block **A*** of order m which has its main diagonal formed by m elements of the main diagonal of **A**.

Let **A*** be a part of the system. For example:

$$A^* = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}.$$

A* can be considered a sub-system of the system **A**. This sub-system is the more autonomous (or, equivalently the less dependent) the greater the values of its elements (a_{11}, a_{12}, a_{21}, a_{22}) are relative to the elements (a_{1j}, a_{2j}, a_{j1} a_{j2}), for all j>2.

In order to measure the greater or lesser autonomy of the sub-system **A***, it can be defined the autonomy degree of **A*** as:

$$G_a(A^*) = \frac{\|A^*\|}{\|A^*\| + \|A^{**}\| + \|A^{***}\|},$$

where $\|M\|$ means "sum of the elements of matrix **M**", **A**** is the block of all the elements of the columns belonging to **A*** with the exception of the elements of **A*** and **A***** means the same for the rows. For example, if **A*** is the block defined above:

$\|A^{**}\| = \sum (a_{j1} + a_{j2})$ and $\|A^{***}\| = \sum (a_{1j} + a_{2j})$ for j = 3, 4, …, N.

Based in the autonomy degree it can be defined a block dependency degree as:

$$G_d(A^*) = 1 - G_a(A^*).$$

It is easy to see that in a matrix **A** of order N there are $2^N - 2$ blocks **A*** (because there are $\sum \binom{N}{k}$ blocks **A*** with k = 1, ... , N-1).

So, the (raw) dependency degree of system **A** is defined as:

$$G^*(A) = \frac{\sum_k G_d(A_k^*)}{2^N - 2}.$$

for which k varies from 1 to $2^N - 2$ and $\mathbf{A_k}$***** represents a square block that includes the main diagonal.

After correcting by the scaling factor given by the maximum value of $G^*(A)$ (that is a function of N):

$$\frac{2^N - 2^{N-2} - 1}{2^N - 2},$$

the **dependency degree** $G(\mathbf{A})$ of **A** is:

$$G(A) = \frac{(2^N - 2)G^*(A)}{2^N - 2^{N-2} - 1}.$$

The **network effect indicator**, $H(\mathbf{A})$ is:

$$H(\mathbf{A}) = 1 - h(\mathbf{A}),$$

with $\mathrm{h(A)} = \dfrac{\mathrm{Z(A)}}{\mathrm{N}^2 - \mathrm{N}}$,

in which $Z(\mathbf{A})$ is the number of zeros of matrix $\mathbf{(I-A)^{-1}}$.

Finally, the complexity as interdependence index combining the dependency and the network effects is:

$$I(\mathbf{A}) = G(\mathbf{A}) \times H(\mathbf{A}).$$

This measure can be based on the technical coefficients matrix (M11 – ADL1) or on the Leontief inverse (M12 –ADL2)

3. Measuring connectedness and complexity with OECD IO data

From the previous section we end up with 12 measures of complexity as input-output connectedness, listed in the table presented in Appendix 1.

In this section we present the results of an empirical application of all these measures using the Input-Output Tables of nine OECD economies in the early seventies and the early nineties of the previous century.

For convenience of analysis the original data is aggregated in the 17 sectors presented in the table of Appendix 2.

Tables 3 and 4 show the main results, that is, the values of all the measures for all the countries in early 70's and early 90's. In Table 5 are the percent changes of values between the 70's and the 90's. Tables 6 and 7 show the correlation coefficients of the absolute values. Finally, Table 8 has the correlation coefficients of percentual changes.

These results give us an interesting inter-country comparison and a time evolution of economic complexity as sectoral interrelatedness.

Looking at the absolute values of these measures, three countries emerge both at the 70's and the 90's: Japan, USA and Germany. At the bottom are the Netherlands, Denmark and Australia. However, the dispersion of countries along the "interrelatedness scale function" seems to decrease notoriously, with a slight overall decrease but no significant relative changes, except UK, upgrading from 9th in the 70's to 4th in the 90's.

A broad inspection of values, noting countries above and below the average of each measure, points to a close behavior of measures CI and ADL1, those that exclude intra-dependence flows. In the sense of complexity as interdependence, these are probably the most appropriate measures. But this conclusion needs further research.

Another way of looking at the results of section 3 in order to identify different concepts of interrelatedness is to give a closer inspection to correlation coefficients. For this purpose we use the following definitions and results.

Let M be the set of the measures m_i, r(i,j) the absolute value of the correlation coefficient between m_i and mj and let c be a number $\mathbf{0 \leq c \leq 1}$.

Definition 1: A **bundle B** of measures of M is a set of elements of M such that for every pair (m_i , m_j) of B we have $r(i,j) \geq c$ and for every m_k of M-B we have at least one m_i of B such that $r(i,k)<c$.

Two bundles B_1 and B_2 are **perfectly separated** when for every m_k of B_1 we have $r(k,i)<c$ for every m_i of B.

Definition 2: An **isolated measure** m_l is one such that the bundle where it belongs is the **degenerate** bundle $\{m_l\}$.

It is easy to see that the family of bundles of the measures of M is a partition of M as the union of disjoint sets. However the set M may be partitioned in several ways.

Assumption (emergent concepts*):* For a set M that is partitioned in perfectly separated bundles, each bundle B is interpreted as the emergence at the surface of a hidden concept of interrelatedness.

When the bundles are not perfectly separated the hidden concepts of interrelatedness are called fuzzy concepts.

It is easy to see that if there is a perfectly separated partition it is the only perfectly separated partition that exists.

Applying these concepts to the results of tables 3-8 and taking for the value of c for each of the years respectively the average of all the correlation coefficients, we have for 70's:

i) two perfectly separated bundles

B_1 = {PIT, AOM, MICTPS, DET, DEA, MPL, CI, STFI, ADL2}

B_2 ={ PNZC, YAM}, and

ii) a degenerate bundle

B_3 = {ADL1} which is also perfectly separated from B_2.

This result indicates that there are probably at least two different concepts of interrelatedness at work, may be a third, although the fact that ADL1 is an isolated measure puts some doubt of it being an expression of a different concept.

The situation changes a little bit for the 90's. We still have:

i) two perfectly separated bundles, but with the exclusion of a measure from the first one:

B_1 ={PIT, AOM, MICTPS, DEA, MPL, CI, STFI, ADL2}

B_2 = {PNZC, YAM}, and

ii) a third non-degenerate bundle

B_3 = {DET, ADL1}.

B_2 and B_3 are also perfectly separable but not B_1 and B_3.

This again indicates that there are at least two concepts of interrelatedness, perhaps three, although two of them are only distinctive in a fuzzy way.

In a sense these results could be expected. Indeed the measures of B_2 take in account, for measuring interrelatedness, the existence or non existence of direct and indirect relations between sectors in a qualitative "Boolean" way.

All the other measures consider the *magnitude* of the relations measured by technical coefficients or multipliers.

4. Conclusions

Connectedness is a crucial feature of input-output analysis that can be used for studying economic complexity as sector interdependence.

There are many ways to quantify connectedness, and it is a useful exercise to confront different measures, both theoretically and empirically.

In this paper, a long menu of twelve measures is presented and briefly discussed. All these measures are quantified using an input-output database of nine OECD countries in the early

70's and 90's, which gives us an interesting inter-country comparison and two decades evolution of economic complexity as sectoral interrelatedness.

Looking at absolute values of the measures it appears to emerge a classification based on excluding intra-dependence flows (CI; ADL1) or not to do so (all the other measures). If economic complexity is defined as sectoral interdependence, CI and ADL1 seem to be the most appropriate indexes, but this deserves further research.

A general view of the results points to three countries being "intensely connected" (Japan; USA and Germany) and three showing low connectedness (Netherlands, Denmark, Australia), all over the period. UK has a peculiar behavior, changing from low to high connectedness between the 70's and the 90's.

In a closer inspection of the values, applying a method of identifying emergent concepts using the correlation coefficients, another classification emerges pointing to the existence of two kinds of interrelatedness measures, a Boolean based group of measures, and a technical coefficient (or output multiplier) based group.

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Appendix 1:

Table 1: Input-Output Connectedness Measures

Number:	Designation:	Formula:	Proponents:
M1	PIT	$100\frac{i'Ax}{i'x}$	Chenery and Watanable (1958)
M2	AOM	$\frac{1}{n}i'(I-A)^{-1}i$	Rasmussen-Hirschman (1958)
M3	PNZC	$\frac{100}{n^2}i'Ki$	Peakock and Dosser (1957)
M4	MICTPS	$\frac{1}{n}i'Ai$	Jensen and West (1980)
M5	DET	$\frac{1}{\lvert I-A \rvert}$	Wang(1954) Lantner(1974)
M6	YAM	$\frac{1}{n^2}\sum_{i,j}\frac{1}{O_{ij}^{YA}}$	Yan and Ames (1963)
M7	DEA	λ	Dietzenbacher (1992)
M8	MPL	$\frac{i'Xi}{i'y}$	Finn (1976)
M9	CI	$CI=\frac{b}{t}$	Finn (1976)
M10	STFI	$\frac{(t-b)}{t}$	Finn (1976)
M11	ADL1	$I=G\times H$ A_{based}	Amaral, Dias and Lopes (2007)
M12	ADL2	$I=G\times H$ $(I-A)^{-1}{}_{based}$	Amaral, Dias and Lopes (2007)

Appendix 2.

Table 2: Aggregate sectors

1	Agriculture, mining & quarrying
2	Food, beverages & tobacco
3	Textiles, apparel & leather
4	Wood and paper
5	Chemicals, drugs, oil and plastics
6	Minerals and metals
7	Electrical and non-elect. equipment
8	Transport equipment
9	Other manufacturing
10	Electricity, gas & water
11	Construction
12	Wholesale & retail trade
13	Restaurants & hotels
14	Transport & storage
15	Communication
16	Finance & insurance
17	Other sectors

Appendix 3:

Table 3: Connectedness Measures, early 70's values

Country	Year	PIT	AOM	PNZC	MIPS	DET	YAM	DEA	MPL	CI	STFI	ADL1	ADL2
Australia	1968	44.67	1.74	91.00	0.42	8.54	0.96	0.43	1.81	0.86	0.14	0.75	0.41
Canadá	1971	42.29	1.68	100.00	0.39	5.23	1.00	0.42	1.73	0.90	0.10	0.78	0.40
Denmark	1972	31.75	1.47	99.65	0.32	3.38	1.00	0.33	1.47	0.93	0.07	0.79	0.33
France	1972	41.03	1.68	96.89	0.41	8.64	0.98	0.39	1.69	0.87	0.13	0.74	0.38
Germany	1978	40.94	1.76	99.31	0.42	10.54	1.00	0.46	1.69	0.86	0.14	0.73	0.40
Japan	1970	50.52	1.96	97.23	0.48	15.09	0.99	0.50	2.02	0.83	0.17	0.74	0.45
Netherlands	1972	29.76	1.45	91.35	0.30	4.30	0.96	0.37	1.42	0.91	0.09	0.75	0.30
UK	1968	37.56	1.68	93.43	0.39	9.18	0.97	0.43	1.60	0.87	0.13	0.73	0.38
USA	1972	41.92	1.90	100.00	0.48	18.29	1.00	0.46	1.72	0.86	0.14	0.71	0.43

Table 4: Connectedness Measures, early 90's values

Country	Year	PIT	AOM	PNZC	MIPS	DET	YAM	DEA	MPL	CI	STFI	ADL1	ADL2
Australia	1989	38.39	1.72	100.00	0.43	6.63	1.00	0.40	1.62	0.90	0.10	0.77	0.41
Canadá	1990	40.76	1.69	100.00	0.40	6.07	1.00	0.41	1.69	0.89	0.11	0.76	0.40
Denmark	1990	31.66	1.53	99.65	0.36	3.64	1.00	0.31	1.46	0.92	0.08	0.79	0.35
France	1990	37.05	1.68	95.85	0.42	8.09	0.98	0.41	1.59	0.88	0.12	0.75	0.39
Germany	1990	41.06	1.77	99.65	0.45	8.74	1.00	0.42	1.70	0.86	0.14	0.75	0.42
Japan	1990	46.00	1.91	95.50	0.48	18.50	0.98	0.47	1.85	0.84	0.16	0.72	0.43
Netherlands	1986	29.99	1.47	91.70	0.32	3.60	0.96	0.33	1.43	0.92	0.08	0.78	0.32
UK	1990	40.39	1.74	100.00	0.43	9.56	1.00	0.42	1.68	0.86	0.14	0.74	0.40
USA	1990	40.15	1.85	100.00	0.47	12.87	1.00	0.44	1.67	0.86	0.14	0.73	0.43

Table 5: Percent changes of values, between the 70's and the 90's

Country	PIT	AOM	PNZC	MIPS	DET	YAM	DEA	MPL	CI	STFI	ADL1	ADL2
AU	-14.05	-1.18	9.89	1.99	-22.37	4.71	-6.87	-10.19	3.83	-24.37	2.67	1.10
CA	-3.60	0.09	0.00	1.10	16.00	0.00	-0.56	-2.57	-0.88	7.84	-1.81	-1.04
DE	-0.31	3.97	0.00	11.96	7.60	0.00	-4.35	-0.14	-0.36	4.43	0.70	8.36
FR	-9.70	0.35	-1.07	2.01	-6.39	-0.53	4.14	-6.18	1.66	-10.97	1.56	1.32
GE	0.30	0.68	0.35	5.25	-17.08	0.17	-9.26	0.21	0.91	-5.42	2.89	3.64
JP	-8.96	-2.27	-1.78	-0.18	22.60	-0.88	-5.68	-8.38	2.28	-10.73	-2.80	-4.19
NL	0.76	1.63	0.38	6.55	-16.21	0.18	-10.21	0.32	1.27	-12.67	3.71	7.70
UK	7.53	3.55	7.04	8.85	4.17	3.40	-1.26	4.75	-1.00	6.57	1.12	6.33
US	-4.20	-2.56	0.00	-1.99	-29.61	0.00	-4.96	-2.94	0.66	-4.02	2.82	-0.28

Table 6: Correlation coefficients, 70's

	PIT	AOM	PNZC	MIPS	DET	YAM	DEA	MPL	CI	STFI	ADL1	ADL2
PIT	1.00											
AOM	0.91	1.00										
PNZC	0.18	0.28	1.00									
MIPS	0.91	0.99	0.29	1.00								
DET	0.67	0.91	0.25	0.90	1.00							
YAM	0.18	0.28	1.00	0.29	0.25	1.00						
DEA	0.85	0.95	0.14	0.92	0.85	0.14	1.00					
MPL	0.99	0.90	0.15	0.88	0.66	0.15	0.84	1.00				
CI	-0.85	-0.91	0.00	-0.90	-0.84	0.00	-0.93	-0.84	1.00			
STFI	0.85	0.91	0.00	0.90	0.84	0.00	0.93	0.84	-1.00	1.00		
ADL1	-0.37	-0.64	0.11	-0.66	-0.82	0.11	-0.67	-0.33	0.75	-0.75	1.00	
ADL2	0.95	0.97	0.34	0.97	0.80	0.34	0.90	0.93	-0.84	0.84	-0.49	1.00

Note: mean absolute values below main diagonal = 0.66

Table 7: Correlation coefficients, 90's

	PIT	AOM	PNZC	MIPS	DET	YAM	DEA	MPL	CI	STFI	ADL1	ADL2
PIT	1.00											
AOM	0.94	1.00										
PNZC	0.36	0.35	1.00									
MIPS	0.91	0.99	0.40	1.00								
DET	0.83	0.91	0.01	0.87	1.00							
YAM	0.36	0.35	1.00	0.40	0.01	1.00						
DEA	0.95	0.96	0.22	0.93	0.88	0.22	1.00					
MPL	1.00	0.94	0.30	0.90	0.86	0.30	0.94	1.00				
CI	-0.91	-0.93	-0.22	-0.91	-0.90	-0.22	-0.94	-0.91	1.00			
STFI	0.91	0.93	0.22	0.91	0.90	0.22	0.94	0.91	-1.00	1.00		
ADL1	-0.85	-0.91	-0.09	-0.89	-0.93	-0.09	-0.94	-0.85	0.96	-0.96	1.00	
ADL2	0.93	0.97	0.55	0.97	0.78	0.55	0.91	0.91	-0.86	0.86	-0.80	1.00

Note: mean absolute values below main diagonal = 0.74

Table 8: Correlation coefficients between the percent changes from the 70's to the 90's

	PIT	AOM	PNZC	MIPS	DET	YAM	DEA	MPL	CI	STFI	ADL1	ADL2
PIT	1.00											
AOM	0.71	1.00										
PNZC	-0.03	0.15	1.00									
MIPS	0.65	0.96	0.18	1.00								
DET	0.11	0.23	-0.29	0.17	1.00							
YAM	-0.02	0.15	1.00	0.18	-0.29	1.00						
DEA	-0.12	0.11	-0.10	-0.12	0.37	-0.10	1.00					
MPL	0.99	0.74	-0.03	0.67	0.03	-0.02	-0.07	1.00				
CI	-0.80	-0.59	0.24	-0.44	-0.37	0.23	-0.31	-0.82	1.00			
STFI	0.71	0.51	-0.27	0.37	0.49	-0.26	0.36	0.71	-0.98	1.00		
ADL1	0.15	0.15	0.31	0.20	-0.92	0.31	-0.39	0.24	0.21	-0.38	1.00	
ADL2	0.66	0.88	0.21	0.90	-0.21	0.21	-0.22	0.71	-0.37	0.23	0.56	1.00

Note: mean absolute values below main diagonal = 0.41