

# Assessing the economic connectedness of the UK pharmaceutical and digital sectors by Input-Output Analysis

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## Abstract

This paper applies the principles of Input Output Analysis (IOA) to identify key structural dependencies between the pharmaceutical sector, the digital sectors, and all the other sectors in an economy. The computation and visualisation of selected metrics to evaluate the strength of downstream and upstream economic connectedness of the digital and pharmaceutical sectors is demonstrated using digital data collections for the UK national economy. Although the analysis is limited to a single-country and a single reference year for illustrative purposes, the proposed approach is meant to provide a bird's-eye view on how the networked structure of the economic system determines paths of influence between the sectors of interests. Such a top-level view is meant to inform and complement the assessment of individual technology interventions of relevance for the 'digitisation' of end-to-end pharmaceutical supply chains.

**Keywords:** Input-Output Analysis; Structural Path Analysis; economic connectedness; digital economy; pharmaceutical manufacture

## Introduction

The 'digitisation' of end-to-end pharmaceutical supply chains denotes an extensive application of Information and Communication Technology (ICT) to the manufacture of medicines, the provision of digital healthcare services and the collection and communication of biometric patient data. Often, the point of focus is placed on individual technology interventions of relevance for the 'digitisation' of end-to-end pharmaceutical supply chains (e.g., Stegemann, 2015; Rantanen and Khinast, 2015), while little or no attention is paid to the evaluation of the strength of downstream and upstream economic connectedness of the digital and pharmaceutical sectors economy-wide. Defining the digital sector in a national economy is not straightforward. For example, in the UK official statistics the manufacture of pharmaceuticals corresponds to two adjacent activities, while the digital sector involves heterogeneous business establishments across manufacturing and service industries which share the aim to capture, transmit and display data and information electronically (Gough, 2015). The relevant sectors for the scope of this paper are shown in Table 1.

Table 1 Classes of economic activities which identify the pharmaceutical and digital sector. Based on: Gough (2015); ONS (2015)

NACE classification	SIC code		Activity name		
	Aggregate	Detail			
2. Production	21	21.1	Manufacture of basic pharmaceutical products	} Pharmaceutical sector	
		21.2	Manufacture of pharmaceutical preparations		
4. Distribution, transport, hotels and restaurants	26	26.1	Manufacture of electronic components and boards	} Digital sector	
		26.2	Manufacture of computers and peripheral equipment		
		26.3	Manufacture of communication equipment		
		26.4	Manufacture of consumer electronics		
		26.8	Manufacture of magnetic and optical media		
		46	46.5		Wholesale of information and communication equipment
5. Information and communication	58	58.2	Software publishing	} Digital sector	
		61	61.1 – 61.9		Telecommunications
		62	62		Computer programming, consultancy and related activities
14. Other services (non-market)	95	63	63.1 – 63.9	} Digital sector	
		95.1	Repair of computers and communication equipment		

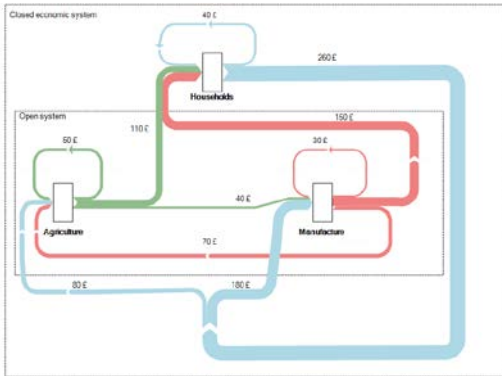
Notes: NACE: Statistical classification of economic activities in the European Community; SIC: Standard Industrial Classification. Aggregate SIC code correspond to the higher level of resolution currently achievable in the UK IOT.

Metrics which refer directly and exclusively to a sector e.g., value added, turnover, and productivity are typically used to express the state of that sector and its relevance for a national economy. For example, in 2014 the food and motor vehicles sectors accounted for a third of the total UK manufacturer product sales, while the pharmaceutical sector experienced a £1.2 billion worth decline in sales (Barnes, 2015); the digital sector accounted for 6% of the UK non-financial business economy turnover in 2013 (Gough, 2015). Whether a sector is ‘key’ economy-wide also depends on how it relates with any other sector within the economy. For example, a sector may be more important for the other sectors than the other sectors are for that sector; or a unit worth expansion of a certain sector may generate more productive activity, or more support to the overall productive activity than others. While sector-specific metrics are provided by international and national statistical offices on a regular basis, the economic connectedness of a sector does not correspond to a single metric, and requires carrying out *ad hoc* computations.

The research presented in this paper illustrates an application of the principles of Input Output Analysis (IOA) to identify key inter-industry linkages between the pharmaceutical sector, the digital sectors, and all the other sectors with a focus on the UK national economy. To achieve this aim, publicly available data from the UK national statistical office (ONS) are processed according to a selection of techniques developed in the field of IOA to measure the strength of downstream and upstream economic connectedness for the sectors of interest (Miller and Blair, 2009).

To the authors’ knowledge, analysis similarly aimed at specific industries have been performed with regards to other contexts e.g. the logistic industry in China (Zhong et al., 2007). While a single national economy and up-front selected sectors are the subject of this research, analogous techniques and principles can be applied to identify and visualise international manufacturing networks from the analysis of structural interdependencies within a group of national economies (Dietzenbacher and Romero, 2007).

Diagrammatic value flow representation (Sankey diagram)



Algebraic representation (Simultaneous equations)

$$(\mathbf{I} - \mathbf{A})\mathbf{x} = \mathbf{y}$$

$$\left\{ \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \right\} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}$$

$$\begin{cases} (1 - a_{11})x_1 - a_{12}x_2 = a_{13}x_3 = y_1 \\ -a_{21}x_1 + (1 - a_{22})x_2 = a_{23}x_3 = y_2 \\ -a_{31}x_1 + -a_{32}x_2 = -(1 - a_{33})x_3 = y_3 \end{cases}$$

$$\begin{cases} x_{11} + x_{12} + x_{13} = x_1 \\ x_{21} + x_{22} + x_{23} = x_2 \\ x_{31} + x_{32} + x_{33} = x_3 \end{cases}$$

Input-output table of the economy

	into	Unit of measurement	Sector 1: Agriculture	Sector 2: Manufacturing	Sector 3: Households	Total output
Sector 1:		Bushels of wheat	25	20	55	100
- Agriculture		(\$)	(50)	(40)	(110)	(200)
Sector 2:		Yards of cloth	14	6	30	50
- Manufacturing		(\$)	(70)	(30)	(150)	(250)
Sector 3:		Man*years of labor	80	180	40	300
- Households		(\$)	(80)	(180)	(40)	(300)

Figure 1 Streamlined representation of an economic system for the purpose of Input-Output Analysis (based on Leontief 1986)

The remainder of the paper is structured as follows: the datasets and techniques applied to achieve the research aim are discussed next, followed by an illustration of the findings gathered from the application of the chosen techniques to the dataset of interest. The findings are then discussed in the light of the ongoing debate regarding the phenomenon commonly referred to as ‘digitalisation’ of the pharmaceutical sector. The closing section wraps up the salient aspects of the methods used and findings obtained, as well as their limitations, and provides directions for future research.

### Materials and methods

Inter-industry, or input-output tables (IOT) of the economy are a common way for national and international statistical offices to portray the supply and use of goods and services in an economy as well as the income generated in that production, while providing a consistent framework to balancing national accounts (see e.g., EUROSTAT, 2008). The basic idea of IOT, and its use in IOA can be concisely described by a streamlined example provided by Leontief (1986) and depicted schematically in Figure 1. Although streamlined, the example describes the principles underpinning most real-world systems of national accounts aiming to provide a comprehensive picture of an economy while taking into account its circular nature.

The example depicted in Figure 1 describes the flows of goods and services within a hypothetical economy consisting of two producing sectors (agriculture and manufacture) over a stated period of time, say a year. It does so through three equivalent representations: 1) tabular (IOT), 2) diagrammatic (nodes and directed arcs); and 3) algebraic (system of simultaneous equations).

If the IOT in Figure 1 is read row-wise it describes how the output of each sector is used up by any other sector for intermediate consumption, and by the households for final consumption. If the IOT is read column-wise, it describes the input structure of the corresponding industry.

An IOT table of the UK economy for a certain year is a symmetric industry-by-industry table that roughly follows the streamlined structure described in Table 2. Most EU member states provide product-by-industry IOTs on a yearly basis, while symmetric product-by-product IOTs are produced for each state on a five-year basis. The latest symmetric product-by-product IOT of the UK economy refers to the year 2010 and will be used through this paper.

A range of metrics of economic connectedness, and corresponding computational techniques have been developed in the realm of IOA (see Miller and Blair, 2009 Ch. 12 for an overview) with some overlap with network science (Barabasi, 2016). The following metrics have been considered for the purpose of this research based on their practical relevance:

- Measures of inter-sectoral backward and forward linkages which express, respectively, the strength of a sector's reliance on the 'rest' of the economy, and the strength of the reliance of the 'rest' of the economy on a specific sector's output;
- Structural decomposition through path multipliers which quantify the amplifying effect due to the presence of nonlinearities on the propagation of influence along sectors-linking paths. The average number of steps necessary for an increase in the final demand of one industry's output to affect another industry's is called Average Propagation Lengths (APL).

For the sake of transparency and replicability, these techniques are applied to the reduced version of the IOT of the UK economy reported in Table 2, at first. Then, the results are computed at a higher level of granularity for the sectors of interest for this research based on a detailed IOT featuring 127 industries. Both tables are built by the UK Office for National Statistics (ONS), and part of a publicly available digital data collection (ONS 2014).

## Findings

The IOT in Table 2 can be used to build a 'demand-driven' input-output model of the UK economy by setting up an appropriate system of linear equations similarly to the one illustrated in Table 1. The equations that make up the basic demand driven, input-output model are concisely expressed using the following matrix notation:

$$\begin{aligned}
 \mathbf{x} &= \mathbf{Z}\mathbf{1} + \mathbf{y} \\
 \mathbf{x} &= \mathbf{Z}\hat{\mathbf{x}}^{-1}\hat{\mathbf{x}}\mathbf{1} + \mathbf{y} \\
 \mathbf{x} &= \mathbf{A}\mathbf{x} + \mathbf{y} \\
 (\mathbf{I} - \mathbf{A})\mathbf{x} &= \mathbf{y} \\
 \mathbf{x} &= (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \\
 \mathbf{x} &= \mathbf{L}\mathbf{y}
 \end{aligned} \tag{1}$$

Table 2 Summary Input-Output Table of the UK economy, 2010 (values in £ billions, rounded). Adapted from (ONS 2014)

		Intermediate uses by industry (NACE code)																	Final uses	Total output	
Output distribution by Industry (NACE code)	From/To	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17			
	1	2.32	8.67	0.19	1.50	0.03	0.00	0.02	0.08	0.02	0.03	0.00	0.00	0.00	0.05	0.00	0.00	0.02	0.00	10.06	22.99
	2	4.28	156.23	24.32	37.83	6.47	3.85	1.80	9.36	5.37	1.99	2.37	0.07	17.38	0.57	0.02	0.93	0.24	0.06	283.39	556.47
	3	0.55	4.42	44.51	18.33	1.62	2.83	17.18	1.89	1.08	0.49	0.14	0.01	5.05	0.11	0.00	0.25	0.06	0.06	111.72	210.24
	4	1.74	33.84	7.17	59.73	5.59	9.82	1.04	8.16	2.68	1.14	0.14	0.07	10.72	0.07	0.02	0.97	0.06	0.06	360.10	503.05
	5	0.21	5.93	2.29	15.93	10.75	12.86	1.84	10.68	1.79	2.15	0.05	0.33	5.07	0.24	0.02	0.50	0.25	0.06	75.64	146.52
	6	1.12	13.90	3.56	11.74	2.93	19.09	42.70	7.64	1.59	1.23	0.02	0.02	4.13	0.03	0.02	0.12	0.11	0.11	112.80	222.76
	7	0.06	0.85	1.11	9.09	0.67	3.03	0.76	0.83	0.51	0.25	0.02	0.02	4.12	0.07	0.00	0.05	0.01	0.01	195.37	216.81
	8	0.39	19.87	16.84	42.45	15.13	26.56	5.41	56.70	4.22	5.57	0.61	0.43	18.18	0.49	0.12	1.10	0.52	0.06	75.61	290.20
	9	0.03	1.66	1.33	4.38	1.28	2.01	4.15	7.05	8.20	0.45	0.01	0.03	36.06	0.00	0.02	2.42	0.09	0.09	41.52	110.69
	10	0.02	0.38	0.08	1.41	1.66	1.09	0.06	1.61	0.87	3.05	0.02	0.27	2.37	0.19	0.00	0.19	1.01	0.06	43.06	57.35
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.17	6.17
	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	3.00
	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	322.78	322.78
	14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.60	4.60
	15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.04	1.04
	16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.99	27.99
	17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.54	8.54
Value added		12.29	310.71	108.84	300.66	100.38	141.61	141.84	186.20	84.35	40.98	2.78	1.76	219.66	2.84	0.83	21.46	6.18	282.37		

Group	NACE code	Description	SIC codes included
Market industry	1	Agriculture	[1-3]
	2	Production	[5-39]
	3	Construction	[41-43]
	4	Distribution, transport, hotels and restaurants	[45-56]
	5	Information and communication	[58-63]
	6	Financial and insurance	[64-66]
	7	Real estate	[68.1-2-68.3]
	8	Professional and support activities	[69.1-82]
	9	Government, health & education	[84-88]
	10	Other services	[90-97]
Non-market - Industry	11	Production (non-market)	[5-39]
	12	Information and communication (non-market)	[58-63]
	13	Government, health & education (non-market)	[84-88]
	14	Other services (non-market)	[90-97]
Non-profit institutions serving households (NPISHS)			[69.1-82]
	15	Professional and support activities (NPISH)	
	16	Government, health & education (NPISH)	[84-88]
	17	Other services (NPISH)	[90-97]

NACE: Statistical classification of economic activities in the European Community; SIC: Standard Industrial Classification

Where:

- x** Column vector of total output. Corresponds to the rightmost column in Table 2
- $\hat{\mathbf{x}}$  Matrix obtained from the diagonalization of vector **x**
- $\hat{\mathbf{x}}^{-1}$  Inverse of matrix  $\hat{\mathbf{x}}$
- Z** Matrix of inter-industry transactions for the reference year. Corresponds to the area defined by the first 17 rows and columns in Table 2
- y** Column vector of demand for the reference year. Corresponds to the first 17 rows of the first to last column in Table 2. Although not displayed in Table 2, the original datasets further distinguishes between consumption by households and government, gross capital formation and exports.
- I** Identity matrix of appropriate dimensions
- 1** Unity column vector of appropriate dimensions
- A** Matrix of direct input coefficients
- L** Leontief inverse, if exists

The matrix equations in (1) are the building blocks of the so called ‘system of quantities’ in IOA, which is thus named although the underpinning variables are typically expressed in some monetary currency - see Leontief 1986. The sum of the elements in the  $j$ -th column of **A** is the amount by which production in sector  $j$  directly depends on inputs from the rest of the economy, while the sum of the elements in the  $j$ -th column of **L** captures both direct and indirect backward dependencies of each sector from all the other sectors. Values for **A** and **L** corresponding to the IOT of the UK economy for the year 2010 are provided as part of the source dataset.

Indexes of direct and total backward linkage can be simultaneously computed for each sector in an economy from the previously obtained matrices **A** and **L** as follows (Miller and Blair 2009):

- Index of *direct* backward linkages,  $\bar{\mathbf{b}}_{\text{direct}} = \frac{n\mathbf{1}'\mathbf{A}}{\mathbf{1}'\mathbf{A}\mathbf{1}}$
- Index of *total* backward linkages,  $\bar{\mathbf{b}}_{\text{total}} = \frac{n\mathbf{1}'\mathbf{L}}{\mathbf{1}'\mathbf{L}\mathbf{1}}$
- Index of *net* backward linkages,  $\bar{\mathbf{b}}_{\text{net}} = \mathbf{1}'\mathbf{L}\hat{\mathbf{y}}\hat{\mathbf{x}}^{-1}$

where  $n$  is the number of sectors in the economy, and the superscript  $'$  denotes vector or matrix transposition.

Values greater than one in  $\bar{\mathbf{b}}_{\text{direct}}$  or  $\bar{\mathbf{b}}_{\text{total}}$  denote sectors with strong (above average) backward linkages and hence a strong dependency on interindustry inputs. In practical terms, a dollar worth expansion of the output of sector  $j$  with a direct or total backward linkage index larger than another sector  $i$ 's would be more beneficial since more productive activity will be generated throughout the economy, directly or indirectly, due to the interconnection between sector  $j$  and the ‘‘upstream’’ sectors. Values greater than one in  $\bar{\mathbf{b}}_{\text{net}}$  denote ‘‘key’’ sectors that are more important for the other sectors than the other sectors are for them. In practical terms, if a sector  $j$  has a net backward index greater than one the output generated economy-wide by an increase in its final demand is greater than the output generated in sector  $j$  by an increase in all the other sectors’ final demands.

Some works compute forward linkages as the row sum of the elements of the same matrices used to compute backward linkages (e.g., Zhong et al. 2007). In doing so, they implicitly assume a simultaneous increases of one unit in the gross output or in the final demand in every sector. More realistic measures of forward linkages require an input-output model which is driven by the forward interindustry transmission of changes occurring in the value added elements, or primary inputs:

$$\begin{aligned}
\mathbf{x}' &= \mathbf{1}'\mathbf{Z} + \mathbf{v}' \\
\mathbf{x}' &= \mathbf{1}'\hat{\mathbf{x}}\hat{\mathbf{x}}^{-1}\mathbf{Z} + \mathbf{v}' \\
\mathbf{x}' &= \mathbf{x}'\mathbf{B} + \mathbf{v}' \\
(\mathbf{I} - \mathbf{B})\mathbf{x}' &= \mathbf{v}' \\
\mathbf{x}' &= (\mathbf{I} - \mathbf{B})^{-1}\mathbf{v}' \\
\mathbf{x}' &= \mathbf{G}\mathbf{v}'
\end{aligned} \tag{2}$$

Where:

- $\mathbf{x}'$  Transpose of the total output vector  $\mathbf{x}$
- $\mathbf{v}'$  Row vector of value entering the interindustry system through primary inputs. Corresponds to the first 17 columns in the last row in Table 2. Although not displayed in Table 2, the original datasets further distinguishes between compensation of employees, imports, taxes less subsidies on products and on production, and gross operating surplus.
- $\mathbf{B}$  Matrix of direct output coefficients
- $\mathbf{G}$  Ghosh inverse, if exists

Indexes of direct and total forward linkage which express the strength of the interconnection between each sector and the downstream sectors to which it sells its output can be simultaneously computed from matrices  $\mathbf{B}$  and  $\mathbf{G}$  as follows (Miller and Blair 2009):

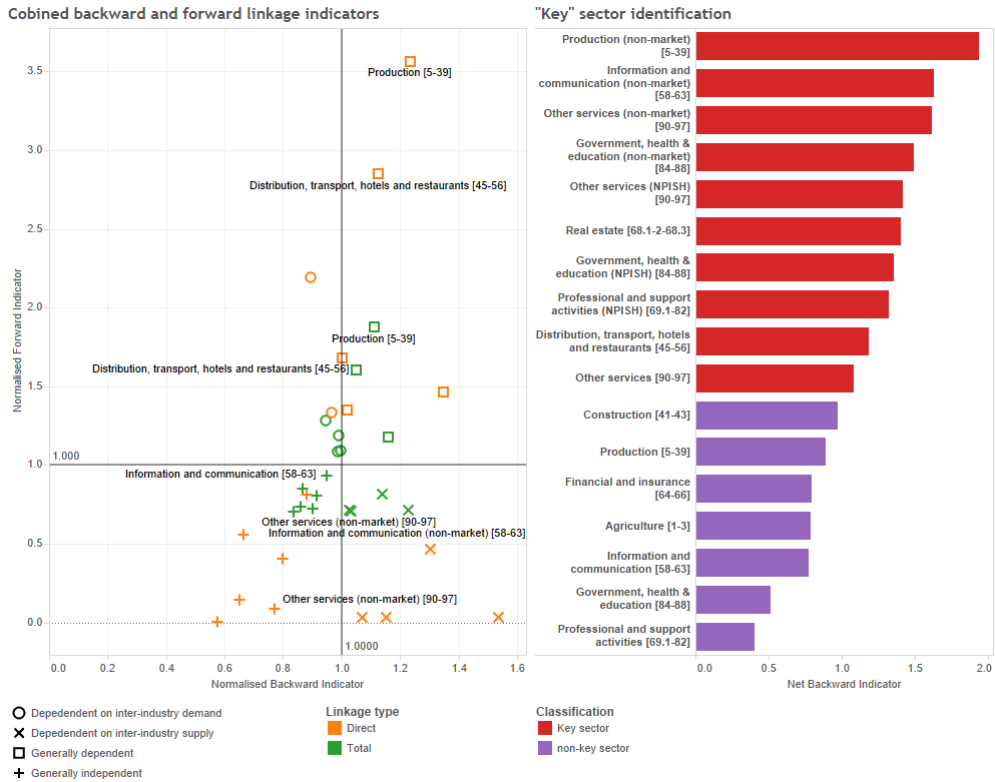
- Index of direct forward linkages,  $\bar{\mathbf{f}}_{\text{direct}} = \frac{n\mathbf{B}\mathbf{1}}{\mathbf{1}'\mathbf{B}\mathbf{1}}$
- Index of total forward linkages,  $\bar{\mathbf{f}}_{\text{total}} = \frac{n\mathbf{G}\mathbf{1}}{\mathbf{1}'\mathbf{G}\mathbf{1}}$

The scores obtained for forward and backward linkages (direct or total) are typically combined to highlight the following types of sectors within an economy:

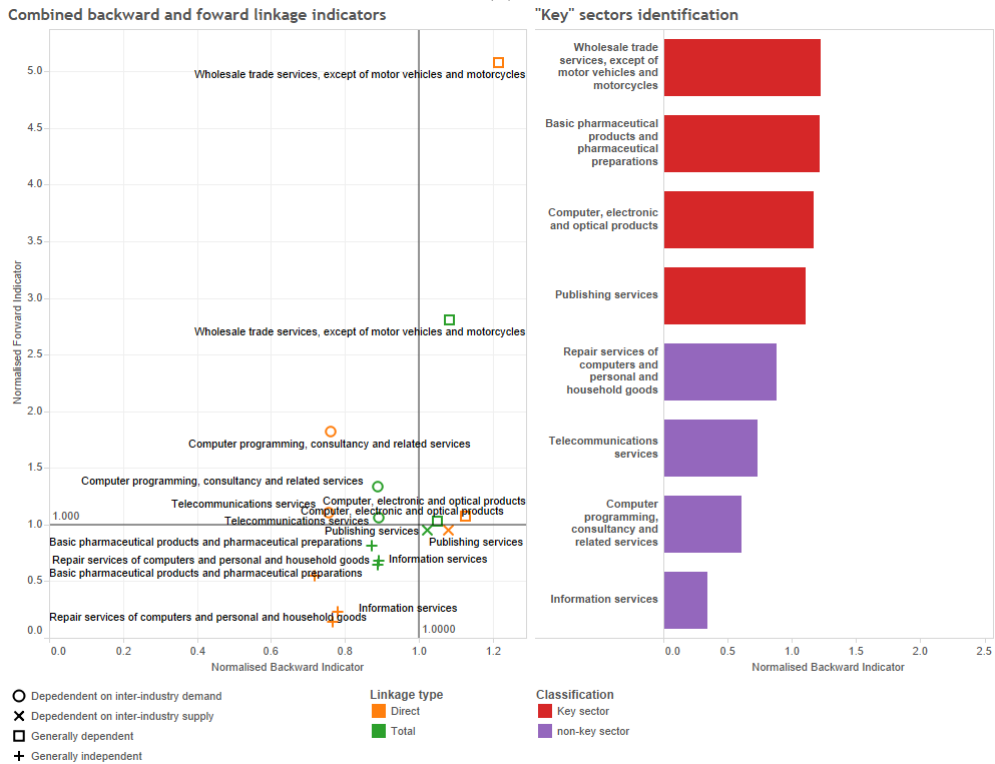
1. Generally independent: both backward and forward linkage indexes are less than one
2. Generally dependent: both backward and forward linkage indexes are greater than one
3. Dependent on interindustry supply: only the backward linkage index is greater than one
4. Dependent on interindustry demand: only the forward linkage index is greater than one

Figure 2(a) visualises the results of computing the above mentioned indexes using data form Table 2. On the right-hand side of Figure 2(a) each of the 17 aggregates is classified based on a combination of its backward and forward linkage indexes, both direct and total. For the sake of readability, labels are shown only for those aggregates which include the sectors of interest for this research as indicated in Table 1. On the left-hand side of Figure 2(a), “key” sectors economy-wise are identified based on their net backward linkage index.

Figure 2(b) shows analogous results at a higher granularity, based on indexes computed for the SIC codes of interest for this research based on data on 127 sectors from the detailed IOT of the UK economy for the year 2010.



(a)



(b)

Figure 2 Classification of sectors based on indicators of backward and forward linkages based on the IOT of the UK economy for the year 2010: a) aggregated summary data and b) detailed data with a focus on the SIC codes of interest as per Table 1



Besides providing measures of the overall strength of a sector's upstream and downstream connectedness, IOA can be used to compute measures of the influence directly and indirectly exerted along the connecting paths that characterise the networked structure of the economic system of interest. Making reference to Table 2, the multitude of interactions among sectors can be visualised as a directed graph where 17 vertices are connected through 165 edges (Figure 3a), which reduces to 3 vertices and 12 edges if the focus is placed on the four aggregates of interest of this research (Figure 3b). The network spanning across the sectors in Table 1 is shown in Figure 3c.

It is common practice to distinguish between the following measures of economic influence along the interconnecting paths within an economy (Defourny and Thorbecke, 1984):

- **Direct influence:** a readily available measure of direct influence is the input coefficients matrix  $\mathbf{A}$  derived in (1). For example, a measure of direct influence along the path having sector 2 (production) as origin of the economic impulse in the direction of expenditure, and sector 5 (Information and communication) as destination is given by the element  $a_{52} = 0.0107$  in matrix  $\mathbf{A}$ . Sector 2 also has a direct influence on sector 4 (distribution), and sector 4 in turn has direct influence on sector 5. The latter is called an influence path of length 2, and a measure of the influence along such path is:  $a_{54}a_{42} = 0.0317 \times 0.0608 = 0.0019$ . There are 10 paths of length 2 between sector 2 and 5, and the corresponding influence metrics are found multiplying element-wise row 2 by column 5 in matrix  $\mathbf{A}$ . Paths of the same or greater length can be investigated for each origin and destination sector in a similar fashion. However, the longer a path the lower its influence.
- **Total influence:** takes into account the amplifying action on the transmission of economic impulses due to the presence of circuits adjacent to an influence paths. For example, in the above mentioned example of a path of length 2 between sector 2 and 5 through sector 4, part of the economic impulse is transmitted back to sectors 4 through an adjacent circuit. A measure of total influence is given by multiplying the direct influence by a 'path multiplier':

$$M_p = \det([\mathbf{I} - \mathbf{A}]_p) / \det(\mathbf{I} - \mathbf{A}) \quad (3)$$

Where:

$\det(\mathbf{I} - \mathbf{A})$	determinant of the matrix $(\mathbf{I} - \mathbf{A})$ obtained in (1)
$\det([\mathbf{I} - \mathbf{A}]_p)$	determinant of the matrix $[\mathbf{I} - \mathbf{A}]_p$
$[\mathbf{I} - \mathbf{A}]_p$	matrix obtained from $(\mathbf{I} - \mathbf{A})$ by eliminating the rows and columns that correspond to the poles along a path $p$ connecting sectors $i$ and $j$ .

In the example  $p = 2, 4, 5$  indicated that sector 2 has a direct influence on sector 4 and sector 4 has a direct influence on sector 5, hence  $[\mathbf{I} - \mathbf{A}]_p$  is obtained by eliminating rows and columns 2, 4 and 5 from  $(\mathbf{I} - \mathbf{A})$ , which yields  $M_p = 1.7707$ . The total influence along the path  $p$  amounts to:  $I_{\text{total}} = a_{54}a_{42} \times M_p = 0.0019 \times 1.7707 = 0.0034$ .

- **Global influence** is the full effect on the output of sector sectors  $i$  due to the transmission of an economic impulse from sector  $j$ . It can be demonstrated that global influence is the sum of the total influences along all the paths spanning two poles  $i$  and  $j$ .

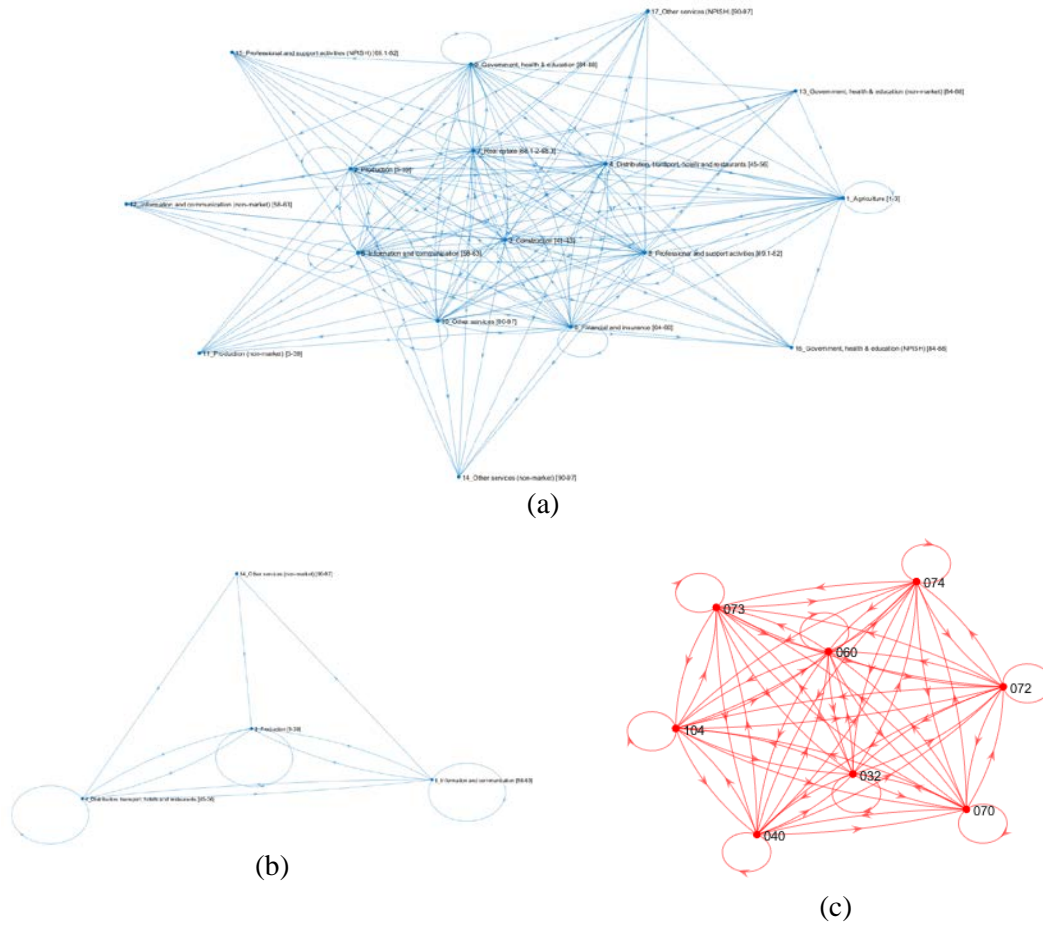


Figure 3 Directed graph representation of the IOT for the UK economy for the year 2010. Using data from the summary IOT, 17 aggregates are shown first (a), 4 of which include the sectors of interest for this research (b). These sectors are shown at a higher level of granularity based on data from the detailed IOT for the same year (c)

A measure of the global influence along two poles  $i$  and  $j$  can be concisely obtained as follows:

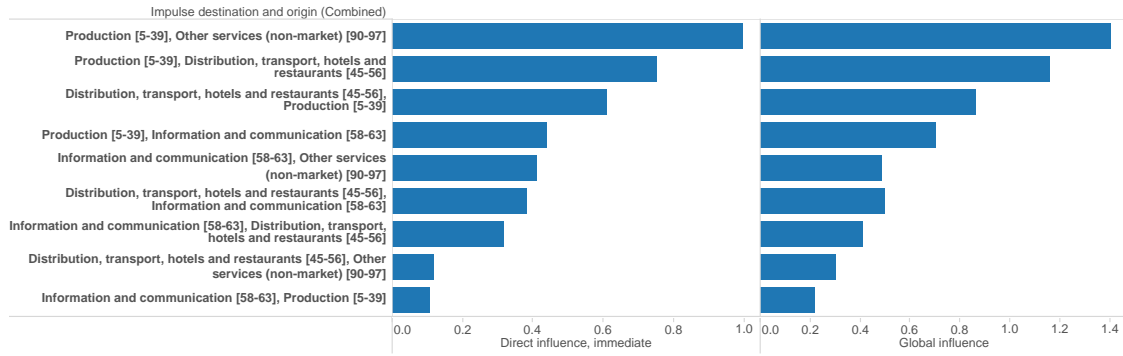
$$I_{\text{global}} = \frac{\Delta_{ij}}{\det(\mathbf{I} - \mathbf{A})} = \frac{(-1)^{i+j} \det([\mathbf{I} - \mathbf{A}]'_{ij})}{\det(\mathbf{I} - \mathbf{A})} \quad (4)$$

Where

$\Delta_{ij}$  Is the  $ij$ -th cofactor of matrix  $(\mathbf{I} - \mathbf{A})$   
 $[\mathbf{I} - \mathbf{A}]'_{ij}$  Is the matrix obtained by eliminating from matrix  $(\mathbf{I} - \mathbf{A})$  row  $j$  and column  $i$  that correspond, respectively, to the impulse originating and the impulse receiving poles along the chosen elementary path.

The measure of global influence sums up the total influences along the multitude of paths spanning two sectors, and corresponds to the element  $l_{ij}$  of the Leontief inverse  $\mathbf{L}$  computed in (1). In the example considered here,  $\frac{\Delta_{ij}}{\det(\mathbf{I} - \mathbf{A})} = l_{ij} = 0.0273$ .

Measures of direct and global influence by destination/origin combination



Top 10 total influences along paths of length 2

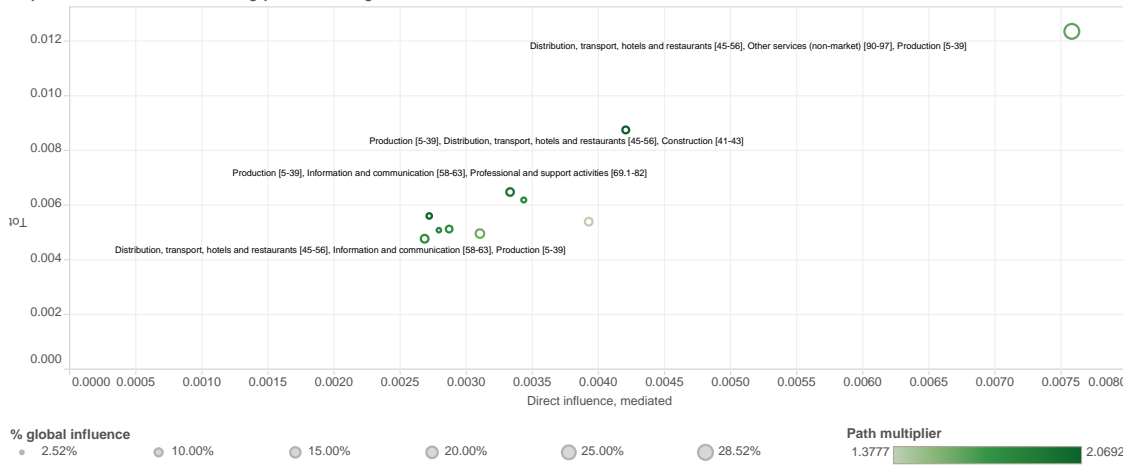


Figure 4 Main influence paths of length 2 for the four aggregates of interest for this research based on the summary IOT of the UK economy 2010.

- Finally, the ratio between total and global influence for a path spanning two poles  $i$  and  $j$  reveals the amount of global influence exercised indirectly through the demand for the output produced by other sectors within the economy. In the example considered here,  $\frac{I_{total}}{I_{global}} = \frac{0.0034}{0.0273} \sim 12.4\%$ .

Figure 4 shows the results of computing the main paths of length 2 between the 4 aggregates of interest for this research alongside the measures of direct and global influence obtained by computing the matrices  $\mathbf{A}$  and  $\mathbf{L}$  in (1). At a higher level of granularity, measures of the direct, indirect and total influence (up to paths of length 2) between the digital and pharmaceutical sectors is shown in Figure 5, with an emphasis on those influence paths having pharmaceuticals manufacturing as the point of origin and as the point destination of economic impulse.

The average number of steps it takes to a backward demand pull (or a forward cost push) originating in a sector to affect the output in another sector is referred to as Average Propagation Length (APL). A measure of APL between two an impulse destination sector  $i$  and an impulse originating sector  $j$  sectors  $i$  and  $j$  can be computed as follows (Dietzenbacher and Romero 2007):

## Top influences to and from pharmaceutical manufacturing

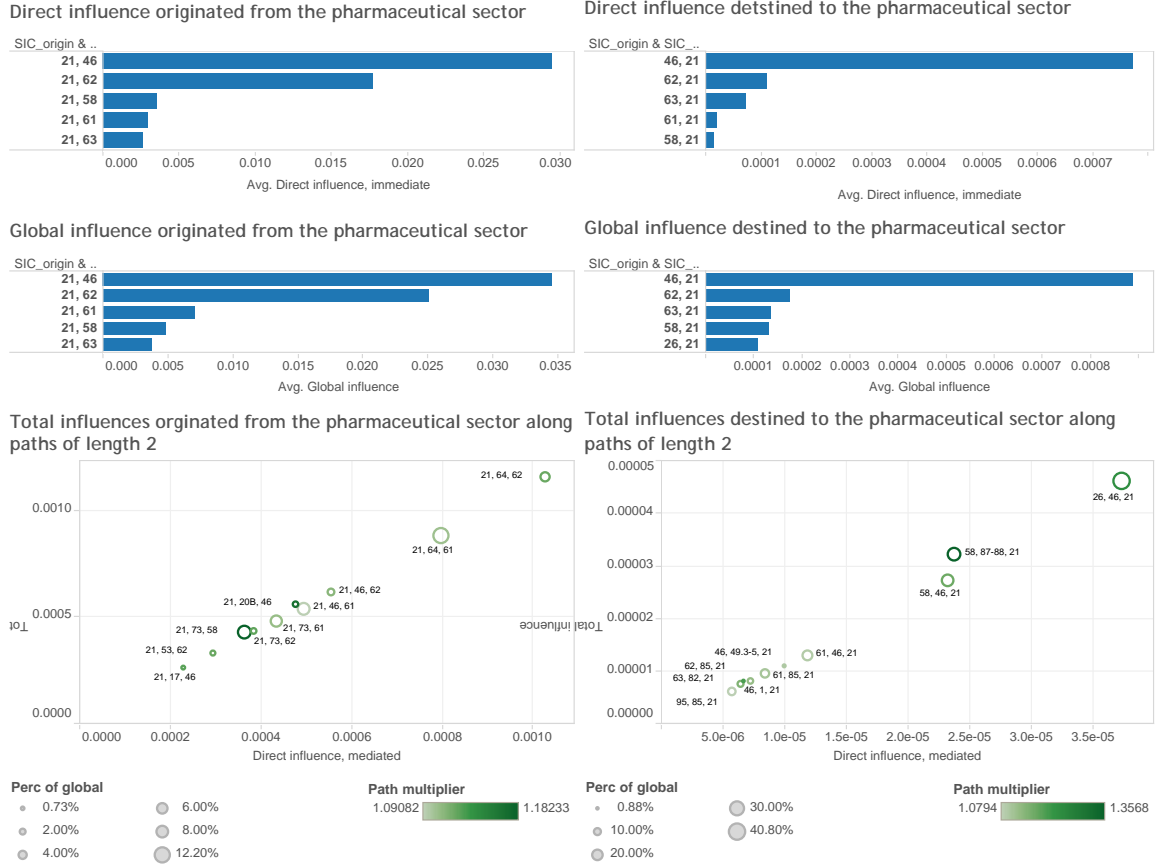


Figure 5 Top influences (direct, global and total) to and from the pharmaceutical sector involving the sectors included in the definition of digital economy. Pairs of numbers denote the SIC codes of the origin and destination sectors; triplets denote the SIC codes of origin, mediating and destination sectors.

$$q_{ij} = \begin{cases} \frac{h_{ij}}{l_{ij}}, & i \neq j \\ \frac{h_{jj}}{(l_{jj} - 1)}, & i = j \end{cases} \quad (5)$$

Where:

$l_{ij}$  Element of the Leontief inverse  $\mathbf{L}$  obtained in (1)  
 $h_{ij}$  Element of the matrix  $\mathbf{H} = \mathbf{L}(\mathbf{L} - \mathbf{I})$

The closer to one is  $q_{ij}$  in (5), the more prominent are the direct dependencies compared to the indirect linkages between two sectors  $i$  and  $j$ . The application of (5) to the Summary IOT of the UK economy in 2010 suggests that only one linkage, namely between agriculture and the financial and insurance sector, is larger than 3.00. Linkages which are either direct or mediated by a single step prevail at this level of aggregation. Results obtained at a higher level of granularity for the manufacture of pharmaceuticals are shown in Figure 6.

### Discussion

At the highest level of aggregation in Table 1, the evidence presented in the previous section suggests that in 2010 the UK production and distribution sectors are ‘generally dependent’, having above average (strong) backward and forward linkages, both direct and total. Conversely, information and communication technology and other services are ‘generally in-

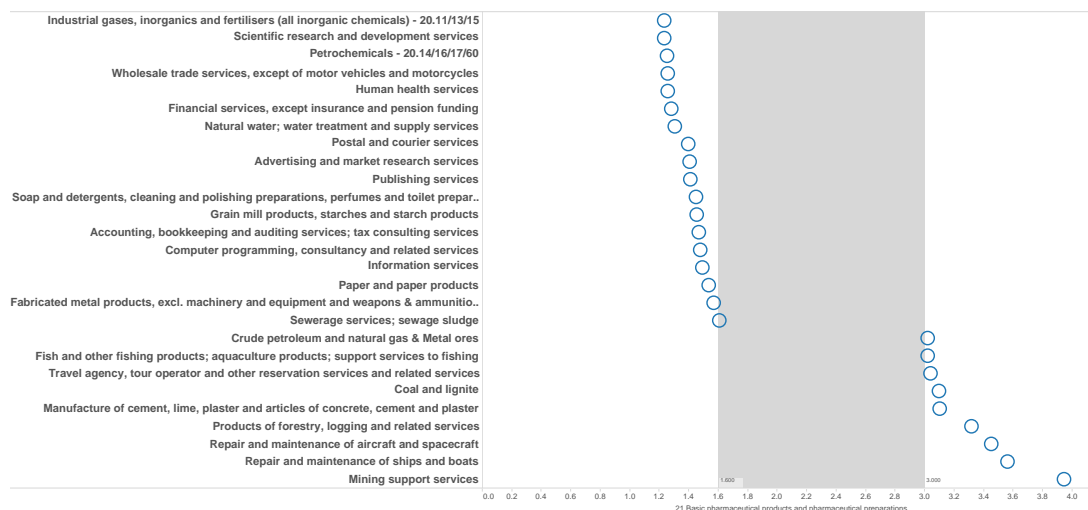


Figure 6 Average Propagation Lengths from the pharmaceutical manufacture sectors (SIC 21), with a focus on below 1.6 and above 3 steps

dependent' for the opposite reason. Hence, a dollar worth expansion of the output of production and distribution is expected to generated and support more productive activity throughout the economy than an expansion of the same magnitude in information and communication or other services.

At a more granular level, however the picture is varied. The manufacture of pharmaceuticals (SIC code 21) is 'generally independent' when considered individually, and so are the 2 SIC codes included in the other services aggregate: information service activities (SIC code 63) and repair of computers and communication equipment (SIC code 95). Of the remaining 5 SIC codes making up the digital economy those sectors included within the information and communication aggregate are either dependent on inter-industry demand (62 - Telecommunications, and 61 - Computer programming, consultancy and related activities) or dependent on inter-industry supply (58 – publishing). Finally, the relevant SIC codes included in the wholesale distribution aggregate (26 - computer, electronic and optical product) and 46 (wholesale trade services) are both generally dependent although sector 26 is only slightly so. With the exception of wholesale and distribution, most of the sectors of interest for this research have weak economic connectedness with the rest of the economy, and hence it is not the case that an expansion of the sector's output is more beneficial compared to other sectors' in terms of economic activity and support generated for the reset of economy. However, the sectors included in the information and communication aggregate show either a strong backward linkage or a moderately strong forward linkage.

At the aggregate level, the key sectors in terms of 'net' backward linkage mostly belong to the non-market economy. Among the aggregates of interest of this research, only distribution and other services qualify as 'key', although in the lower end of the range. At a greater level of granularity, the manufacture of pharmaceuticals as well as the two sectors included in the distribution aggregate qualify as 'key', meaning they are more important for the rest of the economy than the rest of the economy is for them. For the manufacture of pharmaceuticals, this may be due to its weak dependency on other sectors within the UK economy, whereas for distribution its key role reinforces its strong connectedness.

Analysis of the direct input coefficients and the elements of the Leontief inverse for the relevant sectors listed in Table 1 (Figures 5) reveals that the direct immediate, and global transmission of economic influence between the sectors of interest happens primarily along the path spanning between the manufacture of pharmaceutical (SIC 21) and the wholesale sector (SIC 46), followed by the paths between SIC 21 and the sectors included in the Information and communication aggregate: Computer programming consultancy and related activities (SIC 62); publishing (SIC 58), Telecommunications (SIC 61) and Information service activities (SIC 63).

Decomposition of the main elementary paths of length 2 spanning between the relevant sectors listed in Table 1 (Figures 5) provides the following insights:

- Most of the direct and total influences originating from the manufacture of pharmaceutical (SIC 21) is direct toward computer programming, consultancy and related services (SIC 62) and Telecommunications services (SIC 61) via Financial services (SIC 64), Wholesale (SIC 46), and to a lesser extent Advertising and market research services (SIC 73) and Postal and courier services (SIC 53). The path from SIC 21 to SIC 61 through SIC 64 is also the largest in terms of proportion of global influence accounted for (12%). Most influence between SIC 21 and SIC 46 is exerted through Petrochemicals (SIC 20B in the IOT denotes a combination of the SIC codes 20.14/16/17/60), and to a lesser extent through Paper and paper products (SIC 17). This path, and the one from the manufacture of pharmaceuticals to publishing services (SIC 58) through SIC 73 have the largest path multipliers.
- The direct and total influence from the digital economy sectors to SIC 21 is generally much lower than the influence exerted in the opposite direction. The main influence path originates from Computer, electronic and optical products (SIC 26) via Wholesale services (SIC 46). This path accounts for about 41% of the global effect and has the second highest multiplier effect. Another relevant path originates from Publishing services (SIC 58), and reaches SIC 21 through Social care services (SIC 87-88), with the highest path multiplier, or via SIC 46. Of much smaller importance the paths originating from Telecommunications services (SIC 61) via SIC 46 or Education services (SIC 85); from SIC 46 through Land transport services (SIC 49.3-5) or products of agriculture (SIC ); from Computer programming, consultancy and related services (SIC 62) through SIC 85; from information service activities (SIC 63) through Office administrative, office support and other business support services (SIC 82); and from Repair services of computers (SIC 95) through SIC 85.

Figure 6 shows that, at a higher level of granularity, the manufacture of pharmaceuticals has the smallest backward APL ( $< 1.60$ ) with inorganic chemicals (in the IOT this is indicated as a combination of the SIC codes 20.11, 20.13, 20.15); scientific research and development (SIC 72); petrochemicals (a combination of the SIC codes 20.14; 20.16, 20.17, 20.60) and human health services (SIC 86). With the exception of repair services of computers (SIC 95), the APL between the manufacture of pharmaceutical and most of the sectors which in the digital economy is below 2, the smallest ( $< 1.60$ ) being with wholesale trade services (SIC 46), publishing services (SIC 53), Computer programming (SIC 62), and information services (SIC 63).

## Conclusion

This paper has illustrated an approach to identify key inter-industry linkages between the pharmaceutical sector, the digital sectors, and all the other sectors with a focus on the UK national economy in a given year. This aim was achieved through the application of principles developed in the field of Input Output Analysis (IOA) to publicly available empirical data for the UK economy. The approach has generated a range of measures of economic connectedness in terms of 1) reliance of any sector on any other sector within the economy, or backward linkage, as well as reliance of the rest of the economy on the delivery from that sector, or forward linkage; and 2) transmission of economic impulse along a multitude of paths of different lengths spanning any couple of sectors, and the associated amplifying effect due to the presence of circuits adjacent such paths.

The first set of measures led to a classification of the relevant sectors to identify those whose expansion is expected to be more beneficial in terms of activity generated and supported due to the nature of the sectors' connectedness with the rest of the economy, and to the identification of those 'key' sectors that are more important for the rest of the other sectors than the other sectors are for them. The second set of measures was used to explore the main influence paths between the manufacture of pharmaceuticals and the digital sector, and to identify the degree of separation between sectors in term of how many steps it takes for an expansion in the demand of one sector's output to result in an expansion of another sector's output.

The results show that, with the exception of those included in the distribution aggregate, most of the sectors of interest for this research have weak economic connectedness with the rest of the economy, and hence it is not the case that an expansion of the sector's output is more beneficial compared to other sectors' in terms of economic activity and support generated for the rest of economy. The main transmission mechanism of direct and global influence between the sectors of interest happens primarily along the path spanning between the manufacture of pharmaceutical (SIC 21) and the wholesale sector (SIC 46), followed by the paths between SIC 21 and the sectors included in the Information and communication aggregate (including SIC 58, 61, 62, 63). The total influence along paths of length 2 occurs mainly in the direction of expenditure from the manufacture of pharmaceuticals toward the information and communication aggregate (except information service activities - SIC 63) through sectors such as insurance, reinsurance and pension funding services (SIC 65.1-3), rail transport services (SIC 49.1-2), and to a lesser extent other professional, scientific and technical services (SIC 74).

To the authors' knowledge the proposed approach is one of the few attempts to investigate the increasingly relevant relationships between the digital economy and the manufacture of pharmaceuticals from an inter-industry perspective as opposed to stand-alone sector metrics. However, it also has several limitations. In particular, the analysis presented in this paper relies on 'point'-type data for a reference year only, and for a single national economy. Connections with other national economies through imports and exports have been considered as lump sums included in the value added and final demand for each sector, respectively. Other limitations are due to the data since symmetric, product-by-product IOT for the UK national economy are prepared at 5-year interval. Further research should investigate data from a time series perspective to capture how the relationship between the digital and pharmaceutical sector has evolved over time, and expand the analysis from a single country to a group of countries using bilateral trade data. The first task can be achieved by using symmetric industry-by-

industry IOT for the UK economy which are produced at a more regular basis, although these may not be comparable with other EU tables. The former task can be achieved by means of additional resources such as Multi-Regional Input-Output Database.

Despite its limitations, the research presented in this paper contributes to the recent debate on the digitisation of the pharmaceutical sector by providing guidance on the use of well-established techniques such as IOA and publicly available macroeconomic data to provide a system-level perspective on the magnitude and nature of downstream and upstream economic connectedness of these sectors economy-wide which would be not possible to infer from sector specific metrics considered in isolation.

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