A procedure to discern the embodied technological content in goods

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Abstract: The production of goods and services for final demand may require the use of technological inputs, such as direct spending on research and development (R&D) and other technological services. An economy's dynamism depends largely on how these inputs shape the production structure. In this work, we implement a computational procedure to obtain the total technological content, both direct and indirect, embodied in the goods available for final demand, including exports. This methodology enables us to categorize productive activities based on their technological content and reveal the underlying structural patterns. We illustrate this methodology's possibilities using input-output data from the Spanish economy.

Keywords: Technological inputs; Total technological content; Input-output R&D data

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1. Introduction

Commodity accounting allows us to decipher the total volume of an input that is necessary in the production of any other good—directly and indirectly—when we take into account the whole network on productive interdependencies. The embodied volume reveals to which extent the use of the said input disseminates within the productive structure beyond its observable direct initial use. The higher the dissemination, the more widespread its global use. The non observable use of the input is what these accounting methodologies help in revealing. The dissemination may have a detrimental valuation if the input in question is scarce, water or energy for example, or positive if the use of the input signals some type of socioeconomic advancement, as would be the case of the dissemination of research and development (R&D) inputs or any other inputs associated to technological contributions to production. It is in these types of positively appraised inputs that we will focus our interest here. For instance, we may be interested in knowing the technological content of an economy's exports, and what temporal trend it may follow, as a signal of increasing competitiveness.

Researchers have addressed the issue of technological content descriptively (Galindo-Rueda and Verger, 2016). These authors use aggregate sectorial indicators, such as R&D spending over recorded value added or gross production, to establish a classification of industries into five characteristic blocks. Eurostat's classification for high technological content follows exactly this type of rule and is, moreover, restricted to considering just manufacturing industries (Eurostat, 2014). These statistical descriptive indicators, however, are inherently partial in nature as they overlook the network effects generated by the economic interlocking of sectors, a characteristic feature of production in real-world economies. To have a more comprehensive view of the nature of the issue we need to incorporate these network effects into the analysis. This requires distinguishing between immediate (or direct) effects and interaction (or indirect) effects.

The usual approach within the economics literature for conducting these calculations involves using the input-output (I-O) or the social accounting matrix (SAM) frameworks. These methodologies compute linear multipliers, the interpretation of which provides an approximation to commodity accounting (Miller and Blair, 2009; Dietzenbacher, 2005; Sancho, 2012). Nonetheless, these techniques tend to be somewhat mechanistic in nature, and their theoretical foundation has been deemed to be somewhat lacking (Ten Raa, 2005). An alternative approach is the use of commodity accounting as first proposed by Manresa et al. (1998). They suggest an extension of the modern representation of the classical theory of value based on labor (Morishima, 1973) to any other physical commodity. Under this extension, the existence of an economic surplus in any physical commodity is formally equivalent to the classical concept of positive surplus value (Vegara, 1979). This equivalence result lends theoretical support to this type of commodity accounting since it reveals underlying economic viability properties for the system as a whole.

In Section 2 we summarize the formal approach that will allows us to calculate the technological content embodied in each and all commodities. Section 3 describes the empirical side of the paper in terms of data requirements and accommodations, and evaluation results. Section 5 briefly concludes the text.

2. Methodology

We follow Manresa et al (1998) and adapt their proposal to our computational aims. Consider an economy with i=1,2, …, n physical goods/inputs such that the technological input ("tech input" from now on) is assumed to be located in the n-th position for notational simplicity. We use a partitioning of Brody's matrix (Brody, 1970) under this commodity presentation:

$$\mathbf{B} = \begin{pmatrix} \mathbf{A}_{(n-1,n-1)} & \mathbf{A}_{(n-1,n)} & \mathbf{c}_{(n-1)} \\ \mathbf{A}_{(n,n-1)} & \mathbf{A}_{(n,n)} & \mathbf{c}_{(n)} \\ \mathbf{l}_{(n-1)} & \mathbf{l}_{(n)} & \mathbf{0} \end{pmatrix} \qquad (1)$$

where $\mathbf{c}$ is a $(n \times 1)$ column vector defined as the vector of physical consumptions per unit of labor used in this economy and $\mathbf{l}'$ is a $(1 \times n)$ row vector that denotes the direct labor requirements per unit of each commodity i=1,2,…, n. Brody's matrix contains the direct input requirements of all goods both in production and in consumption. The full interindustry production technology is presented in a (n×n) square matrix production function **A**. We distinguish the specific tech good in **A** from the rest of inputs 1, 2, …, n-1 both by row and by column. This will allow us to visualize the tech input requirements for all other interindustry inputs and all other inputs requirements for the production of the tech input.

In general terms, the calculation of total tech content, direct and indirect, follows from, firstly, extracting the n-th good from Brody's matrix and, secondly, applying the extracted direct tech input requirements over the leftover inverse matrix. This yields total tech content or all goods except for good n itself. We now fill out a few of the basic algebraic details[1].

The extracted direct tech input is the vector $\mathbf{A}_{(n,n-1)}$. The leftover Brody matrix is built from $\mathbf{B}$ extracting the n-th column and n-th row to isolate the remaining network effects among the rest of the n-1 productive sectors plus the consumption requirements. Let us call this leftover matrix as $\mathbf{B}_{(-n)}$. The total tech content vector, denoted as $\boldsymbol{\mu}_{(n)}$, is the sum of the direct tech content $\mathbf{A}_{(n,n-1)}$ plus the indirect tech content resulting from the application of the total tech content over the leftover matrix:

$$\boldsymbol{\mu}_{(n)} = \mathbf{A}_{(n,n-1)} + \boldsymbol{\mu}_{(n)} \cdot \mathbf{B}_{(-n)} \tag{2}$$

From here we can solve for total tech content for all goods except the extracted good n:

$$\boldsymbol{\mu}_{(n)} = \mathbf{A}_{(n,n-1)} \cdot (\mathbf{I} - \mathbf{B}_{(-n)})^{-1} \tag{3}$$

The final step consists in determining the total tech content in the production of the tech input itself since, in fact, the quantity in position n for the vector $\boldsymbol{\mu}_{(n)}$ from the calculation in (3) turns out to be necessarily zero given the nature of the extraction. We therefore need to fill the value of the remaining n-th coordinate. To this effect, notice that the tech content of the tech good proper includes the direct tech content $\mathbf{A}_{(n,n)}$ needed for the production of n plus the embodied total tech content in the extracted inputs $\mathbf{A}_{(n-1,n)}$ that are needed to produce the tech good. This is in fact the correct valuation in position n for the vector $\boldsymbol{\mu}_{(n)}$. We can therefore fill the gap using:

$$\mu_n = \mathbf{A}_{(n,n)} + \boldsymbol{\mu}_{(n)} \cdot \mathbf{A}_{(n-1,n)} \tag{4}$$

This completes the determination of total tech content for all produced goods. Expression (3) supplies the nonnegative values for the first n-1 positions of the sought vector and expression (4) the nonnegative scalar for the remaining n-th position.

[1] We refer to Manresa et al (1998) for the full set of mathematical details.

3. Data and results

We use the latest input-output data published by the National Institute of Statistics of Spain (INE, 2023) for 2020. This symmetric I-O table includes 63 distinct industries comprising the providers of agricultural goods (primary) manufactures (secondary) and services (tertiary). Within the 63 industries we identify and aggregate the industries delivering advanced technological services and inputs into a single industry that provides the tech inputs required by the rest of the industries. The aggregation includes the following industries: Informatic and electronic products (sector 17), Telecommunications (s. 39), Programming and informatic services (s. 40), Engineering and technical services (s. 46), Research and development (s. 47). This leaves us with a reshuffled I-O table comprising 59 industries, with the tech industry placed in position n=59. The list and names of industries that we consider in this study appear in Table 1.

Since the input-output table is expressed in monetary terms of the base year 2020, interpretating the results requires to take into account the usual normalization procedure used for input-output data. In other words, each monetary unit corresponds to a redefinition of physical units in such a way that one physical unit is worth one monetary unit. With this in mind, Table 1 classifies industries according to the total technological content embodied in the delivery of one unit of each good and service. We order the industries from highest to lowest tech content.

[Table 1 around here]

Not surprisingly, the tech industry itself (s. 59) is the most intensive industry in tech content. The delivery of one unit of the tech input requires the use of a total of 0.2938 units of the tech input. Air transportation (s. 32) with 0.2257 and Entertainment broadcasting services (s. 37) with 0.2044 turn out to be the top two most tech intensive industries within the set of non-tech industries. It is worth noting that some activities typically classified as services have a high degree of technological content. This is the case of Travel agencies and tourist operators (s. 41), Homer repair services (s. 56), and Advertising and marketing (s. 43), with 0.1563, 0.1497 and 0.1419 tech content, respectively.

This is indeed a bit intriguing because the presence of technology content is usually associated with the delivery of manufacturing products. However, as our results reveal, this a priori intuition is not necessarily correct or substantiated, as becomes evident when we take into account the economic network of interdependencies. All activities require the direct and indirect use of technological inputs, whether or not they belong to manufacturing industries, and the model we use can discern and quantify these needs in any industry. In this regard, we observe that among the industries with the lowest technological content, we find a typical manufacturing industry such as Textiles (s. 6), followed by Forestry (s. 2), Agriculture (s. 1), and Real estate services (s. 41), with embodied tech content values of 0.0508, 0.0477, 0.0445, and 0.0223, respectively.

4. Concluding remarks

In this work, we propose a methodology that allows us to calculate, and consequently, reveal the total technological content incorporated in the production of goods. This methodology has two advantages. The first is that it is constructed as a natural extension of the labor theory of value. The second is that it can be implemented using data regularly prepared by national and international statistical agencies. Among the general results that we obtain, we can highlight that manufacturing industries will not systematically contain more technology than other industries, such as is the case of some service providers. Further research could explore temporal comparisons within a country or region so as to evaluate if an economy adopts new production techniques that improve the diffusion of technology.

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Table 1. Total technology content under network effects

S.	Industry	Tech content	S.	Industry	Tech content
59	Tech	0.2938	25	Waste management services	0.0885
32	Air transportation	0.2257	28	Wholesale commercial services except for vehicles	0.0865
37	Entertainment broadcasting services	0.2044	33	Auxiliary transportation services	0.0863
47	Travel agencies and tourist operators	0.1563	21	Furniture	0.0853
56	Homer repair services	0.1497	7	Wood products	0.0844
43	Advertising and marketing	0.1419	15	Metallurgy	0.0840
20	Other transportation material	0.1389	55	Associational services	0.0838
26	Construction	0.1264	14	Other nonmetallic products	0.0824
34	Postal services	0.1242	11	Chemical products	0.0822
31	Maritime transportation	0.1234	27	Motor vehicle commercial services	0.0813
46	Employment related services	0.1207	29	Retail commercial services except for vehicles	0.0812
48	Auxiliary services to firms	0.1184	44	Other professional services	0.0798
19	Motor vehicles	0.1159	23	Energy	0.0788
36	Publishing services	0.1147	35	Hostelry services	0.0787
49	Public Administration services	0.1141	24	Water treatment and distribution	0.0776
17	Electrical equipment	0.1120	13	Rubber and plastic products	0.0772
52	Social services	0.1100	8	Paper products	0.0765
40	Auxiliary services to financial and insurance	0.1041	39	Insurance services	0.0755
10	Coke and petroleum refining	0.1039	53	Cultural services	0.0755
9	Printing of recorded media	0.1037	38	Financial services	0.0735
18	Machinery	0.1009	12	Pharma products	0.0728
58	Household produced services	0.0992	45	Rental services	0.0724
22	Repair and installation of machinery	0.0977	3	Fisheries	0.0713
42	Legal and accounting services	0.0960	5	Foodstuffs. beverages. and tobacco	0.0694
54	Recreational services	0.0957	57	Other personal services	0.0532
16	Metallic products except machinery	0.0947	6	Textiles	0.0508
4	Extractive industries	0.0938	2	Forestry	0.0477
50	Education	0.0910	1	Agriculture	0.0445
51	Health services	0.0895	41	Real estate services	0.0223
30	Land transportation	0.0886			

Source: Own elaboration