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A new identification method of economic large shocks in the input–output framework: application to the COVID-19

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Abstract

The COVID-19 pandemic has had a significant and unprecedented impact on the global economy, affecting both supply and demand in various industries. The literature on the pandemic has mainly focused on evaluating its real-time impact, using input–output analysis as a toolset. However, this paper aims to identify the magnitude of the large shock after observing its impacts on the economy. The proposed methodology adopts the main assumptions usually made in input–output analysis and focuses on the short term, assuming no significant changes in structures and prices. The approach is based on the technique of hypothetical extraction, which is generalized to consider the possibility of a shock simultaneously impacting all industries. Applying this approach to the Moroccan economy to identify the COVID-19 shock at the sectoral level, it appears that the most significant negative shocks were experienced by three industries, namely tourism, transport and mechanical industries, metallurgical, electrical. This is largely due to the nature of these industries, which are more sensitive to production constraints imposed to limit the spread of the pandemic. The results also show that other branches of activity have been severely impacted via the indirect channel of inputs rather than directly by the shock of the pandemic.

Keywords: Large shocks, Input–output analysis, Partial hypothetical extraction, Total hypothetical extraction, Linkages, COVID-19, Morocco

JEL Classification: E32, C67

1 Introduction

The impact of COVID-19 is broad and unprecedented in several respects. First and foremost, it is unprecedented in its scale. Firstly, economic growth reached a level in 2020 that had not been seen in decades in most countries. Secondly, the nature of this shock is also different because it affected both supply and demand. Due to this hybrid nature, the productive system in 2020 was shaken from all sides. Some industries faced constraints on supply while others faced a decrease in demand. A third category of industries was affected via these two channels. In all cases, activity contractions were substantial in the majority of industries.

Since the outbreak of this pandemic, a vast literature has emerged. It first aimed to understand the nature of this shock and its mechanisms of propagation. Subsequently, it focused on the evaluation of the magnitude of this shock on economic and social performance. Most of the impact evaluation methods are part of the toolbox provided by input–output analysis. Examples include the use of Leontief's mixed models (Aazi et al. 2020; Dauvin and Sampognaro 2021), the application of the partial extraction method (Haddad et al. 2020), or the hypothetical block extraction method (Sayan and Alkan 2021).

In general, this literature has been concerned with the real-time impact evaluation of a large shock on economic activity. The aim of this paper is symmetrical to that. The issue is to identify ex post a large shock after observing its impacts on the economy, knowing that in most countries, the magnitude of this original shock is not observed. Answering this question is useful for economic diagnosis, as it is judicious to explain observed developments by the original impulses experienced at the sectoral level. It is also relevant for economic policy purposes, as the nature of shocks and affected industries are important elements to formulate adequate recommendations.

The aim of this article thus consists of the identification of large economic shocks. The approach we propose adopts the input–output analysis framework for its ability to take into account the industry-level dimension. The proposed methodology adopts the main assumptions usually made in input–output analysis. The latter thus focuses on the short term, which means that structures and prices do not undergo significant changes. The other underlying assumption is related to the assumed nature of the large shock. We mean by this the disruptive shocks that substantially disrupt the functioning of an economy as observed before. In the presence of this type of shock, it is more plausible to consider that it dominates the other shocks if they coexist with this large shock. By resorting to strict confinement by States, the COVID-19 shock is more in line with this scenario.

To develop our approach, we start from the technique of hypothetical extraction, developed by Dietzenbacher and Lahr (2013), which is limited to a single industry. Subsequently, we generalize it to take into account the possibility that a large shock simultaneously impacts all industries. Thus, a system whose inversion makes it possible to recover the original shock at the industry level is defined. This approach is then applied to the Moroccan economy to identify the COVID-19 shock at the industry level. This allowed us to identify the shock experienced by industries during the pandemic and to compare them with observed data, which are often confused with the COVID-19 shock.

The paper is organized as follows: Sect. 2 provides a detailed description of our methodology. In Sect. 3, we apply this approach to identify the COVID-19 shock on the Moroccan economy. This section starts with a brief overview of the data used and their treatment. To enhance the clarity of our results, the second subsection presents some stylized facts about the Moroccan production network. The empirical findings are presented and discussed in the final subsection. Finally, Sect. 4 provides the concluding remarks for the paper.

2 Large-shocks identification in the input–output framework

The main objective of this study is to identify shocks at the industry level. This goal necessitates two critical observations. Firstly, such shocks are not directly observable. Nonetheless, certain observations can serve as shock indicators such as business surveys. Unfortunately, these data only cover brief periods of the year, usually a

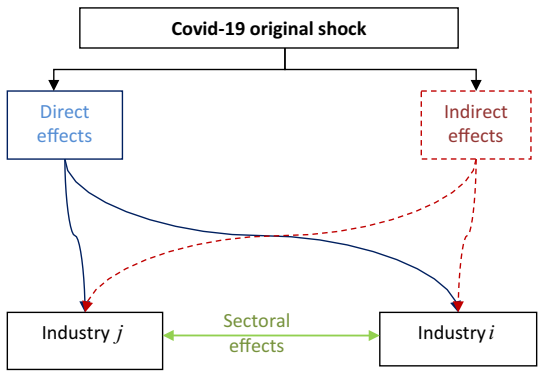

Fig. 1 Shocks and industry interaction. The diagram distinguishes between three types of shocks to COVID-19. The blue solid lines represent direct shocks to the industries (i and j here for the example). The red dashed and broken lines aggregate all shocks indirectly related to COVID-19. The green lines, with arrows in both directions, are the shocks induced due to interactions between the industries

week or month, and are aggregated. Therefore, they are not adequate for evaluating the COVID-19 shock's impact on the industry throughout the year. Similarly, these observations' aggregated nature makes it difficult to discern whether the respondents' difficulties are supply or demand-related.

Secondly, it should be noted that while the large shock experienced by industries is unobservable in this analysis, its effects are observable ex post. In the context of the pandemic, identifying these shocks is equivalent to evaluating the economic system's transition from the pre-COVID-19 situation in 2019 to the post-COVID-19 situation at the end of 2020. These large shocks may be referred to as "original" shocks, as they represent the triggers for the 2019–2020 transition.

This perspective requires further clarification. Input–output analysis at this level can only measure the reciprocal impacts between industries and cannot differentiate between shocks that directly affect the system and those that are induced by the system itself through input flows for production exchanges between industries. Therefore, it is relevant to consider shocks that directly hit the system at time zero as "original" shocks that impact both production and the aggregate economy.

The diagram in Fig. 1 illustrates the underlying mechanism behind the impact of the COVID-19 shock on the industry level. This mechanism can be characterized by the combination of three distinct shocks. The first type of shock (represented by the blue solid lines) is a direct and original shock that directly affects the industries, primarily through supply constraints. The second type of shock (represented by the red dashed lines) aggregates all shocks indirectly linked to the original shock, including fiscal and monetary policies. The third type of shock (represented by the green lines) incorporates the shocks induced by the reaction of industries to these first two types of shocks, reflecting the interactions in the production network. In this study, we focus on the original shocks, which are an aggregation of the first two types (i.e. the blue and red lines). As a result, the original shocks are directly and indirectly linked to COVID-19 shock, and they exclude those that emanate from interactions between industries.

2.1 Starting point: hypothetical extraction method

The starting point of our methodological proposal is the hypothetical extraction method. This method was first proposed by Paelinck et al. (1965), Schultz (1977), Strassert (1968) and then by Clements (1990). It consists of evaluating the importance of an industry in the economy by quantifying the consequences of its removal from the productive system. It is thus the most suitable, among the range offered by input–output analysis, for modelling and measuring the impact of exceptional phenomena.

The main idea of this method is to hypothetically extract or remove a specific industry from the economy and determine the resulting loss of output. This loss is estimated by the difference between the output achieved in the baseline scenario and that achieved after extraction. The total extraction of that specific industry j from the economy implies that this industry, due to its exclusion from the economic system, no longer buys inputs from, or provides inputs to, other industries.

Formally, the supply–demand balance underlying the input–output analysis implies that the output of each industry is used as intermediate inputs by other industries and as final demand (Miller and Blair 2009). Thus, we have:

$$x = Z + f = Ax + f, \tag{1}$$

where x is the column vector of the outputs of the different industries,f is the column vector of the final demands for production of the different industries and Z is the matrix of intermediate inputs.$A = Z.\hat{x}^{-1}$ is the matrix of technical coefficients with $\hat{x}^{-1}$ the inverse matrix of the diagonalized vector x. The extraction of the jth industry is done by eliminating the elements of the jth column and the jth row of the A matrix, which gives a new matrix of technical coefficients, denoted $\overline{A}$. Also, the jth element of the vector f (final demand addressed to industry j) will be replaced by zero (which becomes $\overline{f}$). In this case, the realized output $\overline{x}_T$ after extraction of the jth industry is obtained by:

$$\overline{x}_T = \left(I - \overline{A}\right)^{-1}\overline{f}, \tag{2}$$

with:

$$\overline{x}_T = \begin{pmatrix} \overline{x}_1 \\ \vdots \\ \overline{x}_j \\ \vdots \\ \overline{x}_n \end{pmatrix}, \quad \overline{A} = \begin{pmatrix} a_{11} & \cdots & 0 & \cdots & a_{1n} \\ \vdots & \ddots & 0 & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 \\ \vdots & \cdots & 0 & \ddots & \vdots \\ a_{n1} & \cdots & 0 & \cdots & a_{nn} \end{pmatrix} \text{ and } \overline{f} = \begin{pmatrix} \overline{f}_1 \\ \vdots \\ 0 \\ \vdots \\ \overline{f}_n \end{pmatrix}.$$

Therefore, the loss of total output $\Delta_T x$ as a result of the total extraction of the industry j, is given by:

$$\Delta_T x = x - \overline{x}_T = (I - A)^{-1}f - \left(I - \overline{A}\right)^{-1}\overline{f}. \tag{3}$$

However, while total extraction can measure the impact of extreme events that reduce an industry to nothing, it is not very useful in assessing the impact of partial reduction, rather than annihilation, of an industry's activity. To overcome this situation, Dietzenbacher and Lahr (2013) developed the partial extraction approach. In this case, the aim is to take into account the decline in the industry j. Considering that the activity of the industry j would fall by β, this approach proposes that the intermediate inputs of

this industry as well as its outputs, sold to other industries, will decrease by the same rate β. Formally, the elements of the jth row and the jth column of the technical coefficient matrix A will therefore decrease by β. Thus, all the elements of the jth row will be deflated by being multiplied by $(1-\beta)$ except for the element of the diagonal a_{jj}. This is because all the elements in the jth column will not change. In the end, the intermediate consumption a_j of the industry j will fall in volume as a result of the fall in its output at the β rate. The technical coefficients of the j industry (production function of the j industry) will not change. The final demand for the industry j will also fall at the same rate,[1] the element f_j must be multiplied by $(1-\beta)$. Formally, system (1) becomes:

$$\begin{pmatrix} \overline{x}_1 \\ \vdots \\ \overline{x}_j \\ \vdots \\ \overline{x}_n \end{pmatrix} = \begin{pmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots & \vdots & \vdots \\ (1-\beta)a_{j1} & \dots & a_{jj} & \dots & (1-\beta)a_{jn} \\ \vdots & \dots & \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{pmatrix} \begin{pmatrix} \overline{x}_1 \\ \vdots \\ \overline{x}_j \\ \vdots \\ \overline{x}_n \end{pmatrix} + \begin{pmatrix} \overline{f}_1 \\ \vdots \\ (1-\beta)\overline{f}_j \\ \vdots \\ \overline{f}_n \end{pmatrix}. \tag{4}$$

The difference between the initial output and the output obtained/calculated after the implementation of the partial extraction of the industry j is defined by:

$$\Delta_P x = x - \overline{x} = \left(Ax + f\right) - \left(\overline{A}\overline{x} + \overline{f}\right). \tag{5}$$

At this point, it is obvious that $\Delta_P x < \Delta_T x$. Similarly, $\Delta_P x$ depends on both the parameter β and the production technology (contained in the matrix A), whereas $\Delta_T x$ depends only on the latter.

2.2 Methodology for identifying the original shocks

The proposed methodology for estimating the shocks that cause the disruption of the economic system following the COVID-19 outbreak takes the partial extraction method as a starting point. To do so, we generalize the partial extraction method by assuming the (more realistic) case of multiple and different shocks, in terms of intensity, that hit simultaneously all industries.

Thus, if we take the situation in 2019 as our starting point (initial equilibrium):

$$x_{2019} = Ax_{2019} + f_{2019}. \tag{6}$$

The COVID-19 shock β_j, $j = 1, 2, ..., n$ exerted contractionary impulses on the industries in a simultaneous manner. It is from these impulses that the new equilibrium

[1] Alternatively, it may be assumed that this demand will be met by some companies in the industry, in which case the element is left unchanged.

situation can be found at the end of 2020[2] after all the interactions between the industries have been put into action:

$$\begin{pmatrix} \overline{x}_1 \\ \vdots \\ \overline{x}_j \\ \vdots \\ \overline{x}_n \end{pmatrix}_{2020} = \begin{pmatrix} a_{11} & \cdots & (1-\beta_1)a_{1j} & \cdots & (1-\beta_1)a_{1n} \\ \vdots & \ddots & \vdots & \vdots & \vdots \\ (1-\beta_j)a_{j1} & \cdots & a_{jj} & \cdots & (1-\beta_j)a_{jn} \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ (1-\beta_n)a_{n1} & \cdots & (1-\beta_n)a_{nj} & \cdots & a_{nn} \end{pmatrix} \begin{pmatrix} \overline{x}_1 \\ \vdots \\ \overline{x}_j \\ \vdots \\ \overline{x}_n \end{pmatrix}_{2020} + \begin{pmatrix} (1-\beta_1)\overline{f}_1 \\ \vdots \\ (1-\beta_j)\overline{f}_j \\ \vdots \\ (1-\beta_n)\overline{f}_n \end{pmatrix}, \tag{7}$$

which can be rewritten in a more compact form:

$$x_{2020} = \overline{A}x_{2020} + \overline{f}_{2019}. \tag{8}$$

The matrix $\overline{A}$ can be broken down as follows:

$$\overline{A} = A - \hat{\beta}\big(A - diag(A)\big) = A - \hat{\beta}A_{ss}, \tag{9}$$

where $\hat{\beta}$ is the matrix $n \times n$ which has the diagonal composed of the impulses β_j:

$$\hat{\beta} = \begin{pmatrix} \beta_1 & & & & \\ & \ddots & & & \\ & & \beta_j & & \\ & & & \ddots & \\ & & & & \beta_n \end{pmatrix}.$$

To find the original shocks, let us note that the vector $\overline{x}_{2020}$ of the output of 2020 (after the effect of COVID-19) is a function of these original shocks, materialized by the β_i and the vector of the final demand f. Thus, we have the following equality:

$$\overline{x} = \overline{A}\,\overline{x} + \overline{f} = g\big(\beta, f\big). \tag{10}$$

Via an inversion of the function $g\big(\beta, f\big)$ where the original shocks will be deduced by:

$$\beta = g^{-1}\big(\overline{x}, f\big) = h\big(\overline{x}, f\big). \tag{11}$$

Equation (7) can be expanded, by incorporating relation (8), as follows:

$$x_{2020} = \Big(A - \hat{\beta}A_{ss}\Big)x_{2020} + f_{2019} - \hat{\beta}f_{2019}$$
$$x_{2020} - A\,x_{2020} + \hat{\beta}A_{ss}\,x_{2020} - f_{2019} + \hat{\beta}f_{2019} = 0.$$

So: $\hat{\beta}\,(A_{ss}x_{2020} + f_{2019}) = f_{2019} - (x_{2020} - A\,x_{2020})$,
where: $\hat{\beta}.\,C = D$,
with C and D as vectors. The impulse or shock that the industry j underwent in 2020 mainly due to the COVID-19 is deduced directly:

[2] The mechanics of the national accounts for the calculation of changes in volume imply that the 2019 aggregates must be in value terms (prices of the same year), whereas those of 2020 must be expressed at the prices of the previous year (i.e. of 2019). In this context, it is crucial to bear in mind that aggregates computed at chain-linked prices are inconsequential for the current undertaking, as they lack summability and fail to satisfy macroeconomic equilibrium requirements.

$$\beta_j = \frac{D_j}{C_j}, \tag{12}$$

where according to a matrix formulation: $\hat{\beta} = \hat{D}\,\hat{C}^{-1}$.

3 Application to the COVID-19 in Morocco

3.1 Economic landscape during the pandemic

The COVID-19 pandemic has been a never-experienced shock to all the world's economies, endangering not only the economy, but also the health and well-being of people. It has also been diffused, impacting almost every industry. By the end of 2020, economic activity in both developed and developing countries had contracted by more than 5% according to the World Bank and the International Monetary Fund. According to international agencies, job losses have reached a record level, with more than 250 million jobs lost and the increase in poverty has reached 2.3%.

The impact of this pandemic is also significant on the Moroccan economy, as indicated by the evolution of the main economic aggregates during the year 2020 (see Table 1). Thus, the growth of the national economy fell drastically by 0.9% in the first quarter of 2020 and by 14.2% in the second quarter of 2020, during which the COVID-19 shock peaked. The containment and social distancing measures taken by the government in March, April and May led to this sharp contraction in economic activity.

The slowdown in economic activity during this second quarter was most marked in the hotel and restaurant industry (− 90.6%), transport (− 60.4%), trade (− 25.5%), manufacturing (− 22%), construction (− 12.4%), business and personal services (− 14.4%) and electricity and water (− 11.5%). At the macroeconomic level, the decline in economic growth during this quarter is the consequence of the 13.1% drop in domestic demand and the 32.9% fall in foreign demand.

During the last two quarters of 2020, and despite the measures taken by the public authorities to encourage the recovery of economic and social activities, growth remained penalized. It reached − 6.7% in the third quarter. This is attributable to a 6.6% fall in domestic demand and a 13.7% fall in foreign demand. The contraction of activity during this period was most pronounced in the industries of hotels and restaurants, transport, building and public works and trade. The contraction of activity in these industries reached − 65.8%, − 36.3%, − 6.7% and − 10.7%, respectively. In the last quarter of 2020, growth attained − 5.1%.

In the end, it is useful to note that although economic activity declined almost everywhere in 2020, some industries nevertheless grew. The supply industries (agriculture, fishing and mining) on the one hand, and the non-market industries (administration, health and education) on the other, saw increases in activity.

3.2 Used data

The examination of the interdependence of production network is important for understanding the mechanisms of shock propagation. Before presenting our results, however, it is relevant to recall that our calculations are based on the annual national accounts contained in 2019's Supply and Use Table (SUT). We have chosen this year for two reasons: it is both the most recent table and the one that was not yet affected by the

Table 1 Moroccan economy growth between 2017 and 2020. Source: Haut-Commissariat au Plan. (2021b)

Code	Industries	2017	2018	2019	2020				
					Year	Quarters			
						T1	T2	T3	T4
A00	Agriculture, forestry and related services	15.2	3.7	− 5.8	− 8.6	− 5.9	− 7.6	− 10.3	− 10.7
B05	Fisheries, aquaculture	− 8.3	− 11.0	8.3	12.7	11.6	10.5	17.3	11.5
C00	Extraction industry	17.1	4.4	2.4	5.0	− 0.5	7.8	4.2	8.8
D01	Food and tobacco industries	3.4	2.4	1.1	1.1	6	− 1.6	− 2.5	2.5
D02	Textile and leather industries	3.5	3.1	3.1	− 10.6	5.5	− 43.3	1.6	− 6.2
D03	Chemical and parachemical industry	4.6	4.5	5.6	8.8	9.1	3.2	13	9.6
D04	Mechanical, metal and electrical industry	2.2	6.7	4.7	− 18.2	− 7.7	− 49.6	− 15.2	− 0.8
D07	Other manufacturing	− 1.6	0.4	0.7	− 7.7	− 3.3	− 21.1	− 3.3	− 3.1
E00	Electricity and water	3.3	5.3	13.2	− 3.1	− 2.6	− 11.5	1.6	0.2
F45	Building and public works	1.8	0.1	1.9	− 3.8	5.8	− 12.4	− 6.7	− 1.9
G00	Trade	3.2	2.3	2.4	− 10.7	0.6	− 25.5	− 10.7	− 7.2
H55	Hotels and restaurants	11.5	6.0	3.7	− 55.9	− 7.6	− 90.6	− 65.8	− 57.7
I01	Transport	3.7	3.7	6.6	− 32.0	− 8.2	− 60.4	− 36.3	− 22.8
I02	Post and telecommunications	0.8	2.8	2.4	− 1.9	0	− 2.7	− 4	− 1
J00	Financial and insurance activities	3.8	3.4	4.0	− 0.6	1	− 0.1	− 1.2	− 2.2
K00	Real estate, rental and business services	3.6	5.3	5.1	− 0.9	6.3	− 8.5	− 2.5	− 1.4
OP0	Other non-financial services	1.0	1.6	2.9	− 7.1				
L75	General public administration and social security	2.4	2.2	5.0	2.3	4.6	4	2.8	− 2.1
MN0	Education, health and social work	− 0.9	0.7	2.4	1.2	0.8	2.7	3.4	− 2.2
Gross Domestic Product (GDP)		4.2	3.1	2.6	− 6.3	0.9	− 14.2	− 6.7	− 5.1

At the quarterly level, the two industries K00 and OP0 are aggregated as "Business and personal services" industry

COVID-19 shock. This year's SUT, therefore, reflects the recent state of the Moroccan economy before the COVID-19 moment.

The SUT used is transformed into a symmetrical input–output table (IOT), expressed in local products and valued at basic prices. To obtain it, it was necessary to remove all margins, taxes and subsidies (on products) from the original SUT. In the second step, we removed transactions based on products of foreign origin. Thirdly, we applied a matrix transformation (via the production matrix) to recover the symmetric IOT that expresses the links between the industries.[3] Finally, it should also be recalled that we adopted industry classification in 19 industries, which we believe is an appropriate compromise between the criterion of precision and the level of detail desired for the analysis of the structures of the national economy.

[3] For more details, see Beutel (2017) and Elguellab and Ezzahid (2023).

Table 2 Measures of linkages and industry importance by the HEM. Source: authors' calculations

Industries	A00	B05	C00	D01	D02	D03	D04	D07	E00	F45
TBL	1.330	1.134	1.151	1.481	1.094	1.281	1.179	1.24	1.185	1.469
TFL	1.554	1.503	1.611	1.200	1.045	1.277	1.261	1.939	1.535	1.046
HEM	0.117	0.010	0.023	0.152	0.038	0.049	0.093	0.044	0.034	0.117
Industries	**G00**	**H55**	**I01**	**I02**	**J00**	**K00**	**L75**	**MN0**	**OP0**	**Average**
TBL	1.249	1.403	1.224	1.269	1.336	1.132	1.262	1.130	1.238	**1.252**
TFL	1.018	1.218	1.239	1.215	1.672	1.414	1.000	1.030	1.233	**1.316**
HEM	0.096	0.036	0.056	0.025	0.051	0.092	0.109	0.064	0.015	**0.064**

This table provides measures of Total Backward Linkage (TBL), Total Forward Linkage (TFL) and the importance of the industry using the Hypothetical Extraction Method (HEM) for all industries (in column). The measure of importance is given by the ratio of the decline in total output following the annihilation of industry *j* in the economic system to the initial total output. The last column (bold) shows the mean of the three measures

3.3 Industries: some stylized facts

To make our results more intelligible, we propose in this section to briefly describe the main stylized facts of the national production system. In this context, we describe the interdependencies between the industries and their importance in the production network. To do this, we use the total backward linkage[4] (TBL) and total forward linkages (TFL) measures of the industries and the hypothetical extraction method.[5]

From the point of view of total backward linkages (TBL), i.e. the demand that each industry addresses to the production system, three industries stand out at this level (see Table 2). These are the food and tobacco industry (D01), construction and public works (F45) and hotels and restaurants (H55) with TBLs of 1.48, 1.47 and 1.40, respectively. These three industries have the highest impacts on the other industries through the demand for production inputs. To a lesser extent, the agriculture, forestry and related services (A00) and financial and insurance activities (J00) industries are characterized by relatively high TBL (1.33 and 1.34, respectively). For the lowest TBLs, the textile and leather (D02), education, health and social work (MNO), real estate, renting and business activities (K00) and fishing and aquaculture (B05) industries show the lowest backward linkages.

On the supply side, the most important total forward linkages (TFL) are, in order, those of the industries: other manufacturing (D07), financial and insurance activities (J00) and the mining industry (C00). Their TFLs are 1.94, 1.67 and 1.61, respectively. The five industries that stand out with a very low supply linkage are the public industry (industries L75 and MN0), trade and repair (G00), textiles and leather (D02) and construction (F45).

The weight of the industries, apprehended by the hypothetical extraction method, reveals the importance of the agri-food industry (D01) and the agricultural industry (A00) (see Table 2). Four other industries stand out in this register. These are general public administration and social security (L75), trade (G00), mechanical, metal and electrical engineering (D04) and real estate, renting and business activities (K00). The

[4] The total backward linkage is calculated as column sum of the Leontief matrix $(I\text{-}A)^{-1}$. The total forward linkage is calculated by the matrix $(I - B)^{-1}$, where B is the Ghosh's matrix.

[5] For methodological aspects, please refer to Miller and Blair (2009).

industries of least importance are the two supply industries of fishing, aquaculture (B05) and mining and quarrying (C00), and the industry of other non-financial services (OP0).[6]

3.4 Looking for the large COVID-19 shocks

The COVID-19 crisis affected different industries of the economy, depending on their nature and the structure of their links with other industries. The original shock impacting an industry spreads throughout the economy via processes of productive interdependence through the use of inputs. Ultimately, what we observe represents the aggregation of these direct and indirect effects of the pandemic on the industry.

When analyzing the β values obtained, it is clear that the magnitude of the original shock varies from one industry to another. Industries such as tourism (H55), transport (I01), mechanical, metallurgical and electrical industries (D04) and the textile and leather industry (D02) experienced strong or moderate negative shocks, reaching − 55.65%, − 32.23%, − 15.75% and − 11.38%, respectively. Other industries also experienced negative initial shocks, but these were relatively small in scale. These include trade (G00), agriculture, forestry and related services (A00), other manufacturing (D07), other non-financial services (OP0), and construction (F45).

In contrast to these industries, others experienced positive shocks. The fishing and aquaculture industry (B05) was impacted by a positive shock of moderate magnitude, reaching 13.35%. The chemical and parachemical industry (D03), the food and tobacco industry (D01), the extraction industry (C00), real estate, rental and business services (K00), general public administration and social security (L75), post and telecommunications (I02), finance and insurance (J00), education, health and social work (MN0), and electricity and water (E00), were affected by low-intensity shocks (see Fig. 2 and quantified results in Table 3).

If we refer to these results, it is clear that the industries with significant downward trends were largely driven by the original COVID-19 shocks. This can be explained by the nature of these industries, which were more sensitive to the containment measures imposed by the government to limit the spread of the pandemic, and by the weight of these industries' own effects relative to induced effects.

However, this configuration is not valid in the case of other industries. At the other extreme, we can distinguish industries where the positive evolution of their output at the end of 2020 is mainly attributable to the effects of other industries via input demand. This is the case for real estate, rental and business services (K00), telecommunications (I02) and agri-food industry (D01). In these three cases, positive induced effects from other industries helped to mitigate the COVID-19 shock. On the other hand, in the Financial Activities & Insurance (J00) and Electricity & Water (E00) industries, the original negative COVID-19 shock was fully offset, enabling these two industries to record a positive increase in production in 2020.

In terms of the impact of the pandemic on other industries, the first thing to note is the role of tourism as a channel for spreading the effects of COVID-19. In fact,

[6] More details can be found at Elguellab (2023).

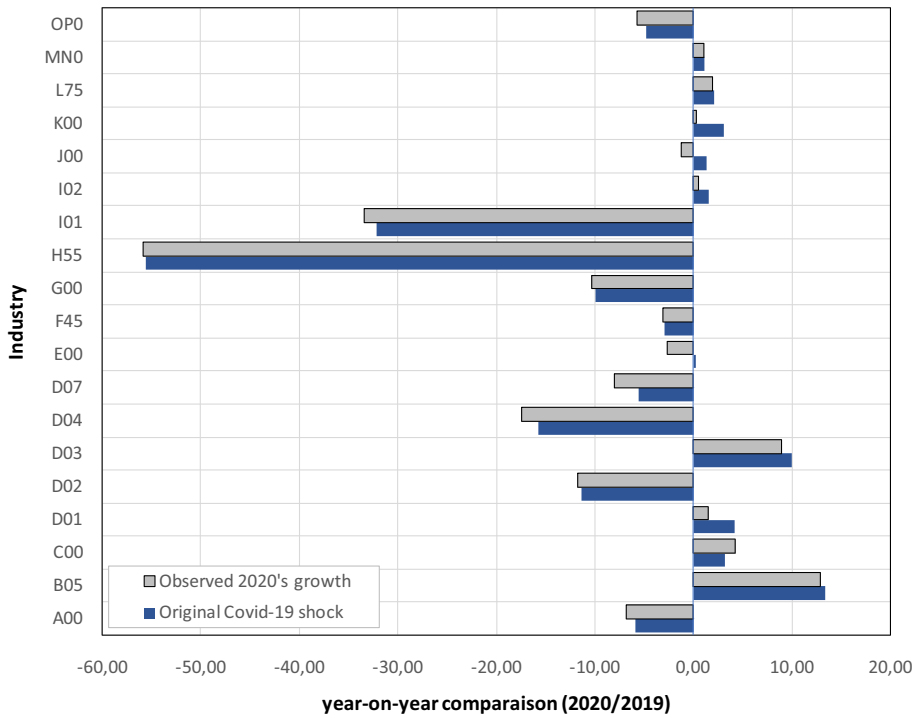

Fig. 2 Original COVID-19 shocks and production developments in 2020. Source: Authors' calculations

Table 3 Original shocks (β) and observed evolution (ex post) of industry-level output (output growth rates between 2019 and 2020 in %). Source: authors' calculations

Industries	Original shocks	Observations (ex post)	Industries	Original shocks	Observations (ex post)
A00	− 5.95	− 6.84	G00	− 9.97	− 10.27
B05	13.35	12.86	H55	− 55.65	− 55.82
C00	3.15	4.27	I01	− 32.23	− 33.41
D01	4.18	1.46	I02	1.48	0.50
D02	− 11.38	− 11.69	J00	1.23	− 1.24
D03	9.91	8.91	K00	3.04	0.25
D04	− 15.75	− 17.47	L75	2.08	1.89
D07	− 5.57	− 8.05	MN0	1.06	1.04
E00	0.18	− 2.71	OP0	− 4.80	− 5.77
F45	− 2.94	− 3.12			

several other industries experienced the consequences of the sharp drop in tourism, namely agri-food (D01), the primary industries of agriculture and fishing (A00 and B05) and electricity and water (E00). As documented in the previous section, these are industries that act more as suppliers of inputs than as demanders from the production system (see Fig. 3).

In the same vein, but with less intensity, the decline in transport activities (I01) pulled down business services (K00) and financial and insurance activities (J00). In addition, activities in the mechanical, metallurgical and electrical engineering industries (D04) also had a significant impact on other industries, particularly the mining industry (C00).

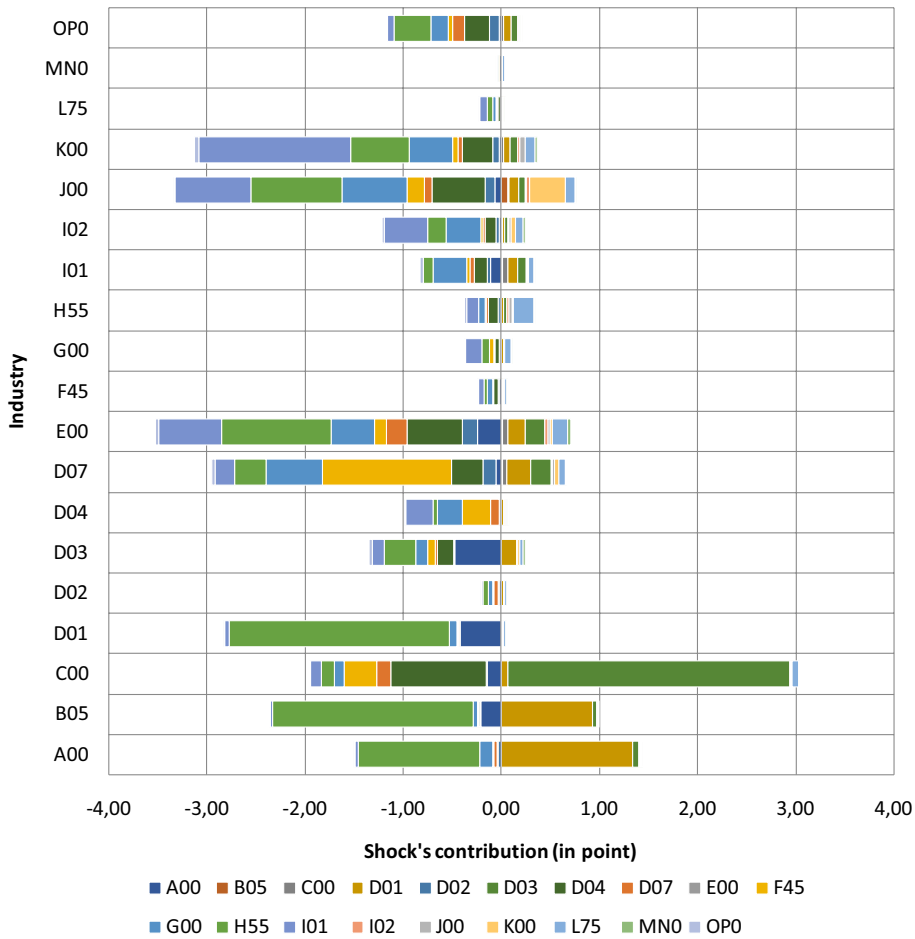

Fig. 3 Intra-sectoral effects of COVID-19 (as % of 2019 production). Source: Authors' calculations

4 Conclusion

This paper proposed a novel approach to identify large shocks at the industry level using the input–output framework. This methodology shares the usual assumptions of input–output analysis; it is, therefore, a short-term analysis which assumes, consequently, the stability of the production's structure and prices. This approach is based on a generalization of the hypothetical extraction method to account for the possibility that a large shock simultaneously impacts differently all industries. Thus, the defined system is inverted to recover the initial large shock at the industry level.

Our approach is applied to the Moroccan economy to identify the COVID-19 shock at the industry level. This allowed us to clarify the shock experienced by industries during the pandemic and to distinguish them from observed data, which are often confused with the COVID-19 shock itself.

The COVID-19 crisis impacted different industries in varying ways depending on their nature and linkages with other industries. Industries such as tourism, transport, and metallurgical, mechanical, and electromechanical industries were severely impacted due to their reliance on supply constraints. On the other hand, industries like electricity and water, food, real estate, renting, business services, and telecommunications benefited from positive effects from other industries, which mitigated the COVID-19 shock. The

financial activities and insurance industry exhibited noteworthy resilience during the pandemic, as it concluded the year with a positive growth, which compensated for the initial adverse effects inflicted by the COVID-19 shock.

Regarding the pandemic's induced effects stemming from other industries, it is evident that the tourism-related industries served as the primary channel for propagating the COVID-19 negative impulsion. Similarly, the decline in transportation activities and in mechanical, metal, and electrical industries' activities exerted significant effects on other industries. In contrast, the positive evolution of the agri-food industry and the chemical and parachemical industry limited the losses experienced by other industries. Overall, the application of this new method to the Moroccan economy produces insightful results and offers a refined understanding of the economic evolution during the pandemic.

This methodology can be improved in several ways. A priori, the shocks that hit the industries can be further explored by distinguishing those that are due to supply constraints from thus that are due to demand constraints. Leontief's mixed model can provide constructive elements in this respect. As a second improvement, final demand can potentially be disaggregated by nature, to consider differences in behaviour between final demanders. Furthermore, an additional distinction can be made between intermediate demand and final demand.

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Author contributions
The COVID-19 pandemic has had a strong impact on global economies, causing severe disruptions across industries. Evaluating the impact of these shocks has been a challenge for economic analysts. However, our method offers an alternative approach to identifying these shocks, which is particularly well-suited for large-scale shocks like the COVID-19 pandemic. Our developed approach is applied to the Moroccan economy and provides insightful conclusions of the economic impact of the pandemic on different industries. Specifically, we are able to distinguish the initial pandemic shock from the observed ex post changes in each industry. This ability provides valuable instruments for policymakers.

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Availability of data and materials
To identify the COVID-19 shock that affected industries in Morocco, we exploited data from the annual accounts of the national accounts contained in the 2019 Supply and Use Table. These data are published by the Haut Commissariat au Plan.

Declarations

Competing interests
The authors declare that they have no competing interests.

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