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THE INOPERABILITY EXTENDED MULTISECTORAL MODEL AND THE ROLE OF INCOME DISTRIBUTION: A U.K. CASE STUDY

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In this paper, an effort is made to enrich the current input–output (I–O) methodologies employed for studying disruptive events, by extending the I–O framework and including all the phases of the circular flow of income into the overall disaster impact. In this respect, the Inoperability Extended Multisectoral Model is created and implemented in order to estimate the higher-order effects in terms of value added and disposable income. The social accounting matrix, referred to the United Kingdom, is constructed and proposed as a starting point for assessing the effects of a system perturbation related to the eruption of the Volcano Eyjafjallajökull, in mid-April 2010, which affected air transport services due to the full closure of the U.K.'s airspace for several days. Finally, the ranking of those commodities and institutional sectors which are badly affected can provide guidance to policymakers in order to minimize the overall impact on the economy.

JEL Codes: D31, D57, Q54

Keywords: disaster impacts, inoperability input–output model, income distribution, social accounting matrix

1. INTRODUCTION

Today, economic systems have become more and more complex and interdependent. The advancement toward a massive and complex society implies realizing and understanding why these interactions have to be considered a critical aspect for the global economy.

The increasing degree of interdependencies, leading to a higher risk and vulnerability among economic activities and institutions, affects society's ability to manage accidents, crises, and disasters. There is a long list of types of recent events—natural and man-made hazards, such as earthquakes, floods, snow

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disasters, hurricanes, or disasters caused by humans—that substantiate this claim and that can trigger consequences in places other than those where they occur. Such disruptive events disturb the whole economic system and lead to a variety of economic losses, including effects on social capital, income, and learning (Yamamura, 2010).

In order to forecast and predict any outcome of an interdependent system failure, a modeling framework that is capable of describing the interdependencies and that involves a careful management of several objectives with multiple level of analysis needs to be constructed.

When studying and analyzing highly interconnected components in an input–output (I–O) framework, an important concept is that of a *key sector* which describes an industry with a strong influence on the expansion of others in an economy (Lahr and Dietzenbacher, 2001), in the same way as disruptions occurring in one sector can trigger interruptions in other sectors, with a magnified effect (Santos, 2006).

The I–O model, as well as the extended I–O model,[1] has been widely used for disaster impact analysis, exploiting the ability (and sometimes tackling the weaknesses) of these accounting frameworks to reflect the detailed economic interdependencies within a national (or regional) economy, and assessing higher-order effects (see, e.g., Okuyama, 2007; Okuyama and Santos, 2014; Baghersad and Zobel, 2015). In this respect, another notable approach for analyzing disruptive events is the inoperability input–output model (IIM) that has been widely proposed and discussed. The theoretical foundations of the IIM can be found in Haimes and Jiang (2001), while the development of the methodologies able to study the inoperability across interdependencies including I–O data are laid out in Santos and Haimes (2004) and Leung *et al.* (2007), among others.

Another important strand of study concerning disaster impact analysis involves the use of social accounting matrix (SAM)–based models. As a notable approach to studying the features of disruptions, SAM-based models have similar advantages and weaknesses to the I–O models, such as the assumption of fixed technical coefficients, a lack of explicit resource constraints, and a lack of responses to price changes (Rose, 2004). On the other hand, the distributional impacts of a disaster can be derived in order to evaluate equity considerations for public policies against disasters (Okuyama, 2007).

Examples of studies using the SAM approach (or one of its variants) in order to examine the higher-order effects include Cole (1995, 1998, 2004), Bradshaw (2003), and, more recently, Okuyama and Sahin (2009),[2] among others.

The effort of this paper is to enrich the current I–O methodologies employed for studying disruptive events by not limiting to the loss on the side of the productive sphere. In fact, this study includes all the phases of the circular flow of income into the overall impact of the disaster, from the allocation and distribution of the income up to the new formation of the final demand. In this context,

[1]Studies using extended I–O models with respect to disaster analysis include Okuyama *et al.* (1999) and Hallegatte (2008).

[2]In this attempt, the construction of the SAMs has followed Miyazawa's approach (Miyazawa, 1976) and the Pyatt and Roe methodology (Pyatt and Roe, 1977) for obtaining the solution of the model.

the Inoperability Extended Multisectoral Model (IEMM) constitutes an evolution of the IIM.

A case study is presented which focuses particularly on the British air transport disruption in the aftermath of the Icelandic volcanic eruption of 2010, considering information from different sources such as the national accounts and sector-specific reports in order to quantify the losses in terms of value added and disposable income percentage variations. A multisectoral analysis for the United Kingdom (U.K.) economy is performed, aimed at portraying the most important source of information for the investigation of the interrelations existing among different interdependent activities associated with air transport services in the U.K. For this purpose, the IEMM is created and implemented in order to analyze and measure the disaster impact scenario and to estimate the resulting ripple effects caused by the disruptive event.

The paper proceeds as follows. Sections 2 and 3 will describe the extended multisectoral model and the demand-side IEMM, respectively. Section 4 focuses on the construction of the 2010 SAM for the U.K., while Section 5 is dedicated to the case study related to the natural disaster that occurred in the U.K.'s airspace and a comparison between the IEMM and the IIM approaches. Finally, concluding remarks are given in Section 6, presenting the ranking of the commodities and institutional sectors that were badly affected and providing guidance to policymakers in order to minimize the overall impact on the economy.

2. The Utilization of Economic Data for Interdependency Analysis

The increasing interest in economic analysis related to income distribution requires the implementation and development of economic tools able to detect transactions among activities and operators of an economic system. The use of extended multisectoral models has been widely discussed (see, e.g., Socci *et al.*, 2014; Ciaschini *et al.*, 2015). This model has been built by following a sequential mechanism that combines a number of structural matrices in order to complete the circular flow of income, extending Miyazawa's approach (Miyazawa, 1976) to other institutional sectors.

2.1. *The Extended Multisectoral Model*

The original structure of the extended multisectoral model is as follows:

$$\mathbf{m}+\mathbf{q}=\mathbf{r}+\mathbf{f}_d, \tag{1}$$

where $\mathbf{m}$ represents the imports vector, $\mathbf{q}$ is the domestic commodity output, $\mathbf{r}$ is the intermediate consumption vector, and $\mathbf{f}_d$ is the final demand vector, composed of an endogenous and an exogenous part, $\mathbf{f}_d=\mathbf{f}_c+\mathbf{f}_0$.

Equation (1) can also be rewritten in terms of domestic commodity output, as follows:

$$\mathbf{q}=\mathbf{r}+\mathbf{f}_c+\mathbf{f}_0-\mathbf{m}. \tag{2}$$

Considering an economy with o commodities, n primary factors, and h institutional sectors, the intermediate consumption vector $\mathbf{r}$ is given by the technical coefficients matrix $\mathbf{A}[o,o]$ multiplied by the commodity output $\mathbf{q}$:

$$\mathbf{r}=\mathbf{A}\mathbf{q}. \tag{3}$$

The technical coefficients matrix $\mathbf{A}$ is composed of the product of the matrix $\mathbf{B}=[\mathbf{U}\hat{\mathbf{x}}^{-1}]$, which represents the inputs value of each commodity by industry output ($\mathbf{x}$), and the matrix $\mathbf{D}=[\mathbf{V}\hat{\mathbf{q}}^{-1}]$, which represents the shares of the commodity output produced by each industry[3].

The net exports vector $\mathbf{f}$ is denoted by

$$\mathbf{f}=\mathbf{f}_0-\mathbf{m}. \tag{4}$$

Substituting $\mathbf{r}$ and $\mathbf{f}$ in equation (2), the extended multisectoral model can also be expressed as follows:

$$\mathbf{q}=\mathbf{A}\mathbf{q}+\mathbf{f}_c+\mathbf{f}. \tag{5}$$

In order to reconstruct the entire process of formation and distribution of income, the I–O value added by commodity $\mathbf{v}_{io}$ needs to be obtained:

$$\mathbf{v}_{io}=\mathbf{L}\mathbf{q}, \tag{6}$$

where $\mathbf{L}[o,o]$ is a diagonal matrix with $l_j=1-\sum_{i=1}^{n} a_{ij}$.

Subsequently, the value added by its components $\mathbf{v}_c$ is introduced as follows:

$$\mathbf{v}_c=\mathbf{W}\mathbf{v}_{io}, \tag{7}$$

where $\mathbf{W}[n,o]$ represents a matrix of shares of primary factors.

Moreover, the value added by the institutional sector $\mathbf{v}_{is}$ is given by

$$\mathbf{v}_{is}=\mathbf{P}\mathbf{v}_c, \tag{8}$$

with $\mathbf{P}[h,n]$ being a shares matrix of the distribution of primary income.

The first phase of the circular flow of income is finalized by the construction of the disposable income vector

$$\mathbf{y}=(\mathbf{I}+\mathbf{T})\mathbf{v}_{is}, \tag{9}$$

which can also be expressed as a function of the domestic commodity output

[3]The matrices $\mathbf{U}$ and $\mathbf{V}$ represent, respectively, the Use and the Make tables, and $\mathbf{x}$ and $\mathbf{q}$ the output by industry and by commodity. For more details, see Miller and Blair (2009).

$$\mathbf{y}=[(\mathbf{I}+\mathbf{T})\mathbf{PWL}]\mathbf{q}. \tag{10}$$

The matrix $\mathbf{T}[h,h]$ represents the shares of the net transfers between the institutional sectors, which take place in the secondary distribution of income.

Defining the matrix $\mathbf{G}=\mathbf{F1C}+\mathbf{K1}s(\mathbf{I}-\mathbf{C})$, the endogenous final demand formation vector $\mathbf{f}_c$ can be written as

$$\mathbf{f}_c=\mathbf{G}[(\mathbf{I}+\mathbf{T})\mathbf{PWL}]\mathbf{q}. \tag{11}$$

The matrix $F1[o,h]$ transforms consumption by the institutional sector into consumption by I–O, while the matrix $\mathbf{C}[h,h]$ is diagonal matrix and each of its elements represents the propensity for consumption by the institutional sector. A part of the final demand formation is composed by $K1[o,h]$, representing the constant shares of investment demands to the I–O commodity by institutional sectors, the scalar s denoting the *active savings*, and the matrix $(\mathbf{I}-\mathbf{C})$ which gives the propensity for saving by the institutional sector.

Denoting $\mathbf{E}=\mathbf{G}(\mathbf{I}+\mathbf{T})\mathbf{PWL}$ and replacing it in equation (11), and then substituting $\mathbf{f}_c$ in equation (5), the structural form of the extended multisectoral model is obtained as follows:

$$\mathbf{q}=\mathbf{Aq}+\mathbf{Eq}+\mathbf{f}. \tag{12}$$

Alternatively, equation (12) can be expressed in its reduced form

$$\mathbf{q}=[\mathbf{I}-\mathbf{A}-\mathbf{E}]^{-1}\mathbf{f}. \tag{13}$$

Solving the model for the value added, we obtain

$$\mathbf{Lq}=\mathbf{L}[\mathbf{I}-\mathbf{A}-\mathbf{E}]^{-1}\mathbf{f}. \tag{14}$$

3. The Inoperability Extended Multisectoral Model

The IEMM approach is developed as an interdependency analysis tool for assessing the ripple effects triggered by various sources of disruption such as natural or man-made disasters. The term *inoperability* is defined as *the inability of the system to perform its intended natural or engineered functions* (Jiang, 2003). In a nutshell, inoperability can be interpreted as a degradation in a system's capacity to deliver its intended output due to an external disturbance or an internal failure.[4]

3.1. *The Demand-Side IEMM*

The IEMM approach is built on the demand-side IIM (also known as the demand-reduction IIM: Santos and Haimes, 2004; Haimes *et al.*, 2005a,2005b),

[4]The original formulation and structure of the model derivation can be found in more detail in Haimes and Jiang (2001) and Santos (2003).

following the reflections and the tweaks suggested by Dietzenbacher and Miller (2015).

The demand-side IIM is an approach usually based on transactional data which reflects interdependencies from the perspective of how the commodities are produced by each sector (Crowther and Haimes, 2005). According to the reflections suggested by Dietzenbacher and Miller (2015), this approach again proposes I–O techniques that are already well known, as in the case of the Ghosh supply-side model described and discussed in Miller and Blair (1985) and seen earlier in Augustinovics (1970). On the other hand, though, the fact that these works opened up this strand of studies related to disaster impact analysis deserves to be acknowledged.

The inoperability measure is introduced in the I–O model following the supply-side I–O model approach, most often associated with Ghosh, through the use of the direct-output coefficients matrix, also called the allocation coefficients matrix, where each of its elements "represent the distribution of sector *i*'s outputs across sectors *j* that purchase interindustry inputs from *i*"; this concept, which is *opposed* to the technical coefficients matrix proposed by Leontief (Miller and Blair, 2009), is of key importance for computing the IIM approach.

Indeed, the demand-side inoperability vector z_i presented in equation (15) is at the core of the IIM approach, where the vector $\bar{q}_i$ is the value of the nominal output without the disruptive event,[5] while the vector $\tilde{q}_i$ is the degraded output after the perturbation:

$$z_i = \frac{\bar{q}_i - \tilde{q}_i}{\bar{q}_i}. \tag{15}$$

Following this consideration, the structural form of the IEMM can be introduced as

$$\mathbf{z} = \mathbf{A}^*\mathbf{z} + \mathbf{E}^*\mathbf{z} + \mathbf{f}^*. \tag{16}$$

Equation (16) describes how the inoperability in each of *o* commodities, manifested in the vector **z**, is brought about by the exogenous final demand perturbation $\mathbf{f}^*$, given by the net exports, that spreads the effect in the direct-output coefficients matrix $\mathbf{A}^*$ and the matrix $\mathbf{E}^*$, which represents the main contribution of this study by introducing the endogenous final demand formation process into the traditional inoperability approach.[6]

[5]In the example presented by Leung *et al.* (2007) and in other publications, a hypothetical I–O table has been considered in which the disaster has not been registered, so that this variable is defined as the "as-planned" production in order to portray a *precise* assessment of the perturbation. In fact, in the I–O tables all the events are already recorded, so the value of the nominal output cannot represent the production without the perturbation. Hence only a *potential* loss assessment analysis can be provided, since the starting framework already considers all the events that occurred in the reference year.

[6]Differently, the mathematical structure of the original inoperability approach applied through the I–O model is presented in the following equations: $\mathbf{z} = \mathbf{A}^*\mathbf{z} + \mathbf{f}^*$, or in a reduced form as $\mathbf{z} = [\mathbf{I} - \mathbf{A}^*]^{-1}\mathbf{f}^*$.

Starting from equation (15), the normalization of each component of equation (16) can be performed, providing the inoperability levels[7] that translate in percentage variations terms the nominal value of the commodity output[8] Therefore each matrix and vector can also be redefined as follows:

$$\mathbf{z}=\hat{\bar{\mathbf{q}}}^{-1}(\bar{\mathbf{q}}-\tilde{\mathbf{q}}), \tag{17}$$

$$\mathbf{A}^{*}=[\hat{\bar{\mathbf{q}}}^{-1}\mathbf{A}\hat{\bar{\mathbf{q}}}], \tag{18}$$

$$\mathbf{E}^{*}=[\hat{\bar{\mathbf{q}}}^{-1}\mathbf{E}\hat{\bar{\mathbf{q}}}], \tag{19}$$

and normalizing the exogenous final demand in the same way as equation (17), we obtain

$$\mathbf{f}^{*}=\hat{\bar{\mathbf{q}}}^{-1}(\bar{\mathbf{f}}-\tilde{\mathbf{f}}). \tag{20}$$

Here, the vector $\bar{\mathbf{f}}$ represents the nominal value of the final demand without the disruptive event, while the vector $\tilde{\mathbf{f}}$ is the degraded final demand after the perturbation.

Having said this, the IEMM can be expressed in an extended version as follows:

$$\hat{\bar{\mathbf{q}}}^{-1}(\bar{\mathbf{q}}-\tilde{\mathbf{q}})=[\hat{\bar{\mathbf{q}}}^{-1}\mathbf{A}\hat{\bar{\mathbf{q}}}]\hat{\bar{\mathbf{q}}}^{-1}(\bar{\mathbf{q}}-\tilde{\mathbf{q}})+[\hat{\bar{\mathbf{q}}}^{-1}\mathbf{E}\hat{\bar{\mathbf{q}}}]\hat{\bar{\mathbf{q}}}^{-1}(\bar{\mathbf{q}}-\tilde{\mathbf{q}})+\hat{\bar{\mathbf{q}}}^{-1}(\bar{\mathbf{f}}-\tilde{\mathbf{f}}), \tag{21}$$

or, alternatively, in its reduced form as

$$\mathbf{z}=[\mathbf{I}-\mathbf{A}^{*}-\mathbf{E}^{*}]^{-1}\mathbf{f}^{*}. \tag{22}$$

At last, the IEMM's value added can be obtained as

$$\mathbf{L}\hat{\bar{\mathbf{q}}}^{-1}(\bar{\mathbf{q}}-\tilde{\mathbf{q}})=\mathbf{L}[\hat{\bar{\mathbf{q}}}^{-1}\mathbf{A}\hat{\bar{\mathbf{q}}}]\hat{\bar{\mathbf{q}}}^{-1}(\bar{\mathbf{q}}-\tilde{\mathbf{q}})+\mathbf{L}[\hat{\bar{\mathbf{q}}}^{-1}\mathbf{E}\hat{\bar{\mathbf{q}}}]\hat{\bar{\mathbf{q}}}^{-1}(\bar{\mathbf{q}}-\tilde{\mathbf{q}})+\mathbf{L}\hat{\bar{\mathbf{q}}}^{-1}(\bar{\mathbf{f}}-\tilde{\mathbf{f}}), \tag{23}$$

or in its reduced form as

$$\mathbf{Lz}=\mathbf{L}[\mathbf{I}-\mathbf{A}^{*}-\mathbf{E}^{*}]^{-1}\mathbf{f}^{*}. \tag{24}$$

In this way, a demand-side reduction brought about by the vector $\mathbf{f}^{*}$ is reflected in the inverse matrix of the IEMM in order to assess the degraded normalized output $\mathbf{z}$ and finally propose the results in terms of value added percentage variations.

[7]The term *inoperability levels* is used to indicate the normalized production loss (Haimes and Jiang, 2001).

[8]"The inoperability model puts the normalization at the beginning; use of the standard Leontief input–output model puts the normalization at the end" (Dietzenbacher and Miller, 2015).

4. The SAM for the U.K.: The Starting Framework

One of the most important issues when measuring inoperability due to a perturbation of the *status quo* is the availability of data (Cavallo *et al*., 2014). Indeed, major information is required in order to support the model effort in the task of assessing the ripple effects activated in the aftermath of a disaster.

In order to address this, the paper avails itself of a SAM that integrates Eurostat's Make and Use tables with the national accounts statistics disaggregated by institutional sector, provided by the U.K.'s Office for National Statistics (ONS). The purpose of employing a SAM is to enrich the current I–O methodologies employed for studying the disruptive events, by extending the I–O framework[9] and by including all the phases of the circular flow of income in the overall impact of the disaster. In order to develop the extended multisectoral model, the 2010 I–O table at basic prices, commodity by commodity (65 products by activity; see also Table A.1, in the Online Supporting Information), has been integrated with *The Blue Book 2014* statistics of the ONS, while assuring uniformity with the integrated economic accounts.

In addition, the SAM framework also includes: (i) three components of the gross value added (GVA): compensation of employees, other taxes less subsidies on production, and gross operating surplus and mixed income; (ii) taxes on products less subsidies on products; (iii) five institutional sectors—households and non-profit institutions serving households (NPISHs), non-financial corporations, financial corporations, central government, and local government; (iv) three components of gross capital formation: gross fixed capital formation, change in valuables, and change in inventories; and (v) the rest of the world.

Table 1 provides a macro-synthesis of the main aggregates: output by commodity and industry, primary allocation of income, secondary distribution, use of disposable income, capital formation, and rest of the world transactions. In this framework, each block can be quantified by its amount. The first row records the following: the intermediate consumption flows required by industry (£1,319,360 million); the final demand consumption by the institutional sector (£1,259,945 million); the part of final demand for capital formation, including gross investments, changes in valuables, and changes in inventories (£244,933 million); and, finally, exports to the rest of the world (£437,225 million). The second row records the total amount of commodities produced by each industry (£2,777,408 million). The first amount in the third row is given by the GVA (£1,400,684 million) that, together with the taxes on products less subsidies (£57,364 million) in the fourth row, represents the gross domestic income (GDI) (£1,558,365 million). The compensation of employees (£1,099 million) generated by border, seasonal, and other workers (residents in the U.K.), jointly with the GDI forms the gross national income (£1,559,464 million).

The fifth row displays: the primary allocation of income, where the value added and the taxes on products less subsidies are distributed to the institutional sectors representing the gross national product (GNP) (£1,558,090 million); and

[9]The accounting scheme keeps the Make (or Supply) table distinguished from the Use table in a commodity–industry accounting framework.

the secondary distribution, collecting all the current and capital transfers between institutional sectors including the rest of the world. The sixth row shows the gross saving for institutional sectors (£214,109 million) and the lending with the rest of the world (£40,583 million). The remaining intersections, in the seventh row, represent the resources from the rest of the world (£484,115 million), and the values of the third and fourth columns (–£1,571 and £2,945 million, respectively), together with the GNP, define the gross domestic product (£1,559,464 million).

The SAM presented in an aggregated version (Table 1) has been implemented, first, in the extended multisectoral model and, second, in the IEMM in its disaggregated form. Therefore, the blocks that include industries and commodities have been employed in Sections 2 and 3 with a commodity by commodity dimension, while the blocks regarding primary factors and institutional sectors have been expanded in the numbers mentioned in the above SAM framework description.

5. A Disaster Impact Analysis: The Case Study

The system of interconnected sectors can be adversely affected as a result of an initial shock on the other sectors, through disruptive events caused by humans or natural disasters. The case study proposed focuses particularly on the air transport disruptions in the aftermath of the eruption of the Icelandic Eyjafjallajökull volcano (in mid-April 2010), which became an international disruptive event that heavily affected air transport services due to the full closure of the U.K.'s airspace for several days.

In order to better present the case study, it is necessary first of all to clarify which are the relevant aspects of these phenomena. Due to the uniqueness of each event, it has to be considered that not all hazards lead to catastrophic consequences (Okuyama, 2007). In fact, each disruptive event has to be treated following the features of the disaster that has occurred, in order to raise more specific considerations in processing the results and in identifying how the analysis should be conducted. In this case study, the volcanic eruption did not affect any infrastructure but only created the inoperability of certain commodities; therefore, it is more relevant to mark the loss in terms of services affected rather than manufacturing products.

Following this consideration, the demand-side IEMM approach can now be implemented in order to assess the higher-order effects in terms of value added percentage variation per commodity (Figure 1) and to offer a comparison with the potential results of the IIM (Tables 2 and 3), underlining the differences between the two disaster impact analyses. By doing this, the potential loss in terms of the decrease in final demand, caused basically by deferred travel and alternative modes of travel, has to be quantified. The value of the reduction in final demand, estimated at £258 million,[10] is simply the difference between the nominal value of the exogenous final demand without the disruptive event ($\bar{\mathbf{f}}$) and the degraded exogenous final demand after the perturbation ($\tilde{\mathbf{f}}$), as shown in equation (20). The consequent premultiplication with the vector $\hat{\mathbf{q}}^{-1}$ offers the value of the reduction in terms of normalized degraded exogenous final demand

[10]The data have been provided by Oxford Economics in their report *UK Economic Losses Due to Volcanic Ash Air Travel Restrictions* (Oxford Economics, 2013).

TABLE 1
The Aggregated Set of Commodity–Industry Data in the 2010 SAM for the U.K.
(Millions of Pounds Sterling)

	Commodities	Industries	Gross Value Added	Taxes on Products Less Subsidies	Institutional Sectors	Capital Formation	Rest of the World	TOTAL
Commodities	0	1,319,360	0	0	1,259,945	244,993	437,225	3,261,523
Industries	2,777,408	0	0	0	0	0	0	2,777,408
GVA	0	1,400,684	0	0	0	0	1,099	1,401,783
Taxes on products less subsidies	0	57,364	0	0	80,786	9,699	9,832	157,681
Institutional sectors	0	0	1,403,354	154,736	1,490,892	0	188,247	3,237,229
Capital formation	0	0	0	0	214,109	0	40,583	254,692
Rest of the world	484,115	0	−1,571	2,945	191,497	0	0	676,986
TOTAL	3,261,523	2,777,408	1,401,783	157,681	3,237,229	254,692	676,986	

Source: Own elaboration on ONS data.

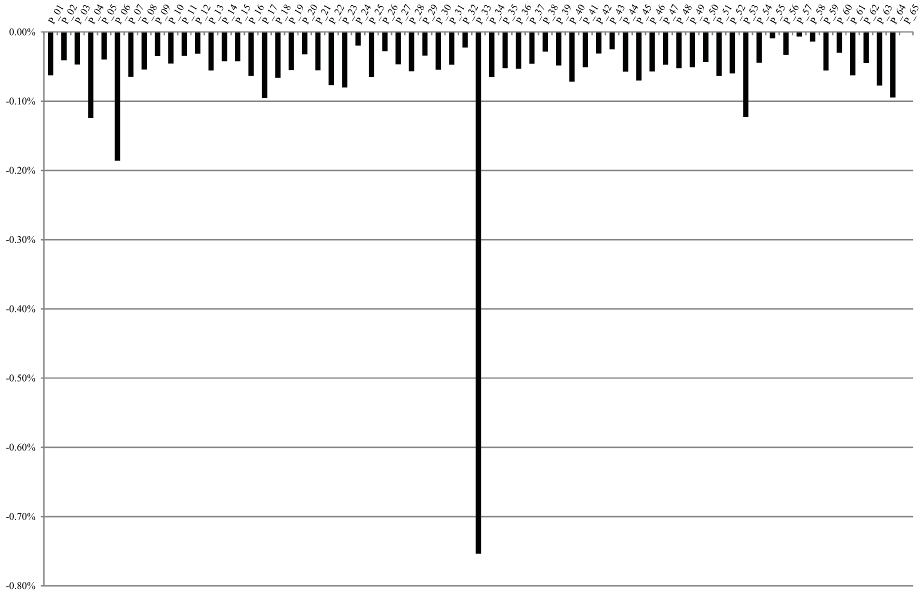

Figure 1. Value Added Loss by Commodity (Percentage Variation, %)

Source: Own elaboration.

TABLE 2

IEMM versus IIM: Top Ten Worst Commodities (Percentage Variation, %)

Id	Commodity	IEMM	IIM
$P_{-}33$	Air transport services	−0.75	−0.71
$P_{-}53$	Travel agency, tour operator, and other reservation services and related services	−0.12	−0.08
$P_{-}64$	Services of households as employers; undifferentiated goods and services produced by households for own use	−0.09	0.00
$P_{-}63$	Other personal services	−0.08	−0.01
$P_{-}40$	Computer programming, consultancy, and related services; information services	−0.07	−0.02
$P_{-}45$	Imputed rents of owner-occupied dwellings	−0.07	0.00
$P_{-}34$	Warehousing and support services for transportation	−0.07	−0.03
$P_{-}51$	Rental and leasing services	−0.06	−0.01
$P_{-}61$	Services furnished by membership organizations	−0.06	0.00
$P_{-}52$	Employment services	−0.06	−0.01
	Total value added	−0.20	−0.04

($\mathbf{f}^*$). The results for the IEMM approach follow the consideration expressed in equation (22), with a further transformation for obtaining the value added percentage variations as shown in equation (24).

The negative values of the goods and services which are immediately affected in the aftermath of the disruptive event are displayed in Figure 1. The commodity receiving the highest level of damage in terms of value added percentage variation is $P_{-}33$, "Air transport services," which directly suffers a demand-side loss; other related services are observed to register a reduction—such as, for instance, $P_{-}53$,

TABLE 3

IEMM versus IIM: Disposable Income Results (Percentage Variation, %)

	IEMM	IIM
Households and NPISHs	−0.09	nc
Non-financial corporations	−0.10	nc
Financial corporations	−0.08	nc
Central government	−0.07	nc
Local government	−0.10	nc
Disposable income	−0.10	nc

"Travel agency, tour operator, and other reservation services and related services," and $P_{-}64$, "Services of households as employers; undifferentiated goods and services produced by households for own use." Further significant results are provided in Table 2 considering only the first ten most affected services with respect to the two approaches, sorted in descending order according to the IEMM's value added percentage variations.

As previously mentioned, the IEMM commodities that are largely damaged in terms of value added percentage variations in the services are $P_{-}33$, "Air transport services," $P_{-}53$, "Travel agency, tour operator, and other reservation services and related services," and $P_{-}64$, "Services of households as employers; undifferentiated goods and services produced by households for own use" (Table 2). While the IIM is able to detect, although at a different scale, the value added reduction mainly in commodity $P_{-}33$, which is the one directly affected, and in $P_{-}53$, relevant variations in the other commodities are not captured. These findings are further confirmed and underlined when observing the results of the total value added percentage variations between the two approaches, the IEMM being once again able to bring out a major reduction of −0.20 percent with respect to the IIM, which can only approximate −0.04 percent.

Table 3 emphasizes this difference between the two approaches. In fact, the results in terms of disposable income percentage variations show the capability of the IEMM to bring out the magnitude of the event, which cannot otherwise be captured using the IIM.

It is now possible to define the loss in the new disposable income formation after the perturbation. In fact, it can be noted that a decrease in final demand of £258 million generates a negative impact to overall disposable income and its components due to a reduction of the production level and a decrease in value added. The table presents five components of disposable income—by households and NPISHs, non-financial corporations, financial corporations, central government, and local government—in addition to overall disposable income, variables that are obtained following the considerations presented in equation (10). Indeed, while the inoperability levels are initially provided in percentage variations terms, $\mathbf{z}$, in order to obtain the results in terms of disposable income and then obtain the percentage variations from the benchmark, a translation back to nominal values (in millions of pounds sterling) is required.[11]

[11]Note that this transformation, which is achieved by postmultiplying $\mathbf{z}$ by $\hat{\hat{\mathbf{q}}}$, is necessary in order not to lose sight of the dimensions of the variables during the calculation process.

Each component of this aggregate receives a different impact. For example, central government turns out to be the lesser affected among all the institutional sectors, followed by financial corporations, by −0.07 percent and −0.08 percent, respectively. Households and NPISHs encounter a reduction of −0.09 percent, while local government and non-financial corporations follow the same trend as the overall disposable income, being affected by a −0.10 percent decrease.

The variables that cannot be obtained using the IIM approach are denoted by "nc" ("not comparable").

6. Final Remarks

The study of methodologies that are increasingly precise in terms of estimating the effects of disruptive events, and are capable of providing a ranking of the economic activities which are badly affected, can provide guidance to policymakers in order to minimize the overall impact on the economy after a system perturbation. The occurrence of catastrophic events linked to the social, environmental, industrial, and health spheres can affect the economic system from both the production side and that of the formation and distribution of income. These disruptive events provoke a contraction in final demand, measured by the official statistics, which in turn has an impact on the natural course of the economic system that would have been recorded in the absence of the event. In this context, one relevant aspect is related to the fact that the production system may not operate because of a lack of final demand, and not because of reasons related to production efficiencies. The consequence of this decrease is to generate an indirect effect due to the contraction of the disposable income, which affects the formation of endogenous final demand.

The use of an I–O model for this type of analysis can only capture the initial appearance by quantifying the direct and indirect impacts linked strictly to the productive sphere. In disaster impact analysis, the assessment of inoperability not only has to take into account the loss at the production level, but also needs to include the return effects on the final demand. The critical aspect of the IIMs is therefore represented by the overall underestimation of the economic impact of the event due to a partial representation of the economic phenomenon.

The inoperability approach combined with a SAM has allowed us to conduct a deeper evaluation of the overall effect, by not just considering the direct and indirect effects, as is the case when using an I–O framework. The possibility of exploiting a larger accounting scheme provides the opportunity to employ all the phases of the circular flow of income and, finally, to obtain the higher-order effects, which also include the induced effects. In fact, in the case of the extended multisectoral model, by estimating the variation of the final demand, the occurrence of the event introduced in the model could generate two potential indirect effects. In the first case, no significant indirect impacts on the value added—and, consequently, on the income generated—might be observed, because key labor- and capital-intensive production operations may not have been affected by the reduction in the final demand. This type of impact analysis of the event can be performed using the IIM approach. In the second case, however, when the contraction of the final demand concerns key production activities that are well integrated into the production system and that create value added relevant to the formation of income, the overall economic impact assessment of the event can be obtained by integrating the effects generated by the productive sphere with those yielded by the income sphere. The IEMM approach carries out this type of impact analysis and, moreover, it is capable of embodying the IIM and further amplifying its potentialities by considering, at the same time, the production impacts and the effects on the income distribution. This extension can attenuate or amplify the impacts of the traditional inoperability model.

Finally, the completeness of the extended model with respect to the short one allows us to provide a full picture of the entire impact of the disaster, which demonstrates it to be a more appropriate and more complete policy decision tool. As presented in Table 2, the IEMM approach not only highlights the direct effect in the commodity $P_{-}33$, "Air transport services," also captured by the IIM although at a lower magnitude, but additionally it also registers considerably higher impacts on the other commodities. Furthermore, in the IEMM approach the outcomes of the analysis take into consideration distributive aspects (Table 3), which allow us to present the results in terms of disposable income by institutional sectors, while the IIM approach could only yield a share of the overall impact regarding the production side.

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Supporting Information

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Appendix
Table A.1: Classification Table