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Uncertainty Importance and Risk-Based Decision Making in the Inoperability Input-Output Model

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Abstract

In this paper we apply a moment-independent sensitivity analysis technique to the Inoperability Input-Output Model to identify the most effective preparedness strategies.

Keywords: Inoperability Input-Output Model; Global Sensitivity Analysis.

1. Introduction

Natural disasters have always been a source of main concern for human beings. The loss of human lives and physical destruction have imposed and still impose a tremendous toll to societies. Earthquakes, floods, vulcano eruptions, hurricanses are among the worst enemies of humanity. Looking into past, De Boer and Sanders (2005) argue that the effects of earthquakes (and in general of natural disasters) are particularly complex and involve several dimensions. The earthquake of Lisbon in 1755, for example, imposed also both a cultural and political change, with the irreversible decline of Portugal as a maritime power. Similar arguments apply in the case of terrorist attacks or, in general, to large-scale manmade disasters.
In recent years, the world has been subject to massive destruction caused by natural disasters which have prompted the attention of scholars into the design of information management architectures (Amin et al., 2008) and preparedness strategies. There is no doubt that natural and manmade disasters have relevant economic impacts in terms of loss of human lives, capital destruction and consumption reduction. By focusing on the contraction of final demand as a consequence of an exogenous shock, Santos and Haimes (2004) have proposed the Inoperability Input-Output Model (IIM). This linear model builds on the classical input-output model in which a change in the aggregate demand propagates to the production through the so-called Leontieff inverse matrix which is a function of technical coefficients. An interesting feature of the model is the consideration of several interdependent sectors, so that a change in the demand for the goods produced in one of those sectors may propagate to the rest of the economy. The IIM has proven to be suitable for the identification of best preparedness strategies.

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In this paper we aim to propose the application of the δ measure of importance to the case of the identification of best preparedness strategies in the IIM framework. To this end we first present the IIM and then introduce the measure of importance.

Let us consider the following formulation:

$$\mathbf{q} = \mathbf{A}^{*}\mathbf{q} + \mathbf{c}^{*} \qquad (1)$$

where **q** is the inoperability vector expressed in terms of normalized loss. The elements of this vector are the ratios of unrealized production with respect to the potential production. c* is the shock in the aggregate demand of the economy expressed in terms of reduced final demand. The structure of A* matrix is as follows:

$$\mathbf{A}^{*} = \begin{bmatrix} a_{11}\left(\frac{\hat{x}_1}{\hat{x}_1}\right) & \cdots & a_{1j}\left(\frac{\hat{x}_j}{\hat{x}_1}\right) & \cdots & a_{1n}\left(\frac{\hat{x}_n}{\hat{x}_1}\right) \\ \vdots & \ddots & \vdots & & \vdots \\ a_{i1}\left(\frac{\hat{x}_1}{\hat{x}_i}\right) & \cdots & a_{ij}\left(\frac{\hat{x}_j}{\hat{x}_i}\right) & \cdots & a_{in}\left(\frac{\hat{x}_n}{\hat{x}_i}\right) \\ \vdots & & \vdots & \ddots & \vdots \\ a_{n1}\left(\frac{\hat{x}_1}{\hat{x}_n}\right) & \cdots & a_{nj}\left(\frac{\hat{x}_j}{\hat{x}_n}\right) & \cdots & a_{nn}\left(\frac{\hat{x}_n}{\hat{x}_n}\right) \end{bmatrix} \qquad (2)$$

where the generic element a_{ij} belongs to the matrix A of technical coefficients in the original Leontief model and x_i is the production potential of industry i. The elements in a given row of matrix in (2) indicate how much additional inoperability is contributed by a column industry to the row industry.

System (1) can be written as:

$$\mathbf{q} = \left(\mathbf{I} - \mathbf{A}^{*}\right)^{-1}\mathbf{c}^{*} \qquad (3)$$

if det[(I-A*)]≠0 and where I is the identity matrix. By construction, elements in vectors q and c* equal zero unless a terrorist attack is perpetrated or a natural disaster occurs. In such a case, the shock on the demand side (i.e., one or more elements in c* become positive) propagates to the economy output through the inverse $(I\text{-}A^*)^{-1}$. In this paper, we are mainly interested in identifying the most effective policies (i.e. those interventions capable to reduce expected economic loss) in a context of uncertainty characterizing all sectors considered in the model. In order to provide a quantitative measure of the importance of a given strategy we apply the δ importance measure (Borgonovo, 2006; Borgonovo 2007). The main advantage of this index is the fact that it is moment-independent, hence it can be applied to concrete cases without approximating output probability distribution to distributions whose mean and/or variance are known in explicit form. In a nutshell, we consider a model consisting in 15 sectors and we characterize them with given probability distributions. By means of Monte Carlo simulation it is possible to draw the probability distribution of total economic loss. We then make some assumptions about possible preparadness strategies, their costs, and eventuelly their impact on probability distributions of sectoral consumption contractions. We then observe the changes occurring in the density function of total economic loss and use them to compute δ importance measures for the considered strategies. The larger the changes, the larger δ is.

2. References

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