**The impact of production and infrastructure shocks to the Japanese inter­regional economy: A non-linear input-output programming approach**

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**Abstract**

This paper develops a methodology to predict and to thus possibly mitigate the economic impacts of major catastrophes, such as earthquakes and tsunamis. The short-run impacts are assumed to be determined by the attempts of economic actors to return to the pre-catastrophe economic situation as closely and as quickly as possible. We propose to model these behavioural reactions by a non-linear program that minimizes the weighted sum of the logarithms of the deviations between the post- and the pre-catastrophe size of all economic transactions in the economy at hand, subject to a Walras-Leontief production function per regional industry, a minimal size of regional final demand by product and a positive trade balance. The non-linear program is considered to be representative of the short-run equilibrium of the economy at hand, if its base scenario solution closely resembles the base year interregional input-output table of the country at hand.

The methodology will be tested by means of the comparison of the base scenario with a series of scenarios with regional production shocks and interregional infrastructure shocks to the Japanese interregional, interindustry economy of 2005. The impacts of these shocks will be evaluated by means of the changes in, respectively, regional value added, the output price by regional industry.

**Keywords**: catastrophe analysis, non-linear programming, input-output analysis, infrastructure shocks, Japan

**1. Introduction**

The basic idea is to capture the short-run equilibrium changes that would occur after a major disaster, such as the 2011 tsunami in Japan. The earthquake and tsunami that struck Japan on March 2011 caused a tragic loss of property and life. In the short-run it is plausible that all economic actors (firms, households, various governments) will try to return to a situation that is as close to the pre-disaster situation as possible. The earthquake and tsunami that struck Japan on March 2011 caused a tragic loss of property and life. To describe this situation, we will use the interregional input-ouput table for Japan for 2005. Utilizing interregional input-output model is to estimate of domestic impacts of the supply shock due to the unscheduled natural disasters. The aim of this paper is to study the economic impacts of production and infrastructure shocks of the natural disaster in general with the interregional input-ouput table for Japan for 2005.

Ideally, estimating these impacts requires the ‘bottom-up’ interregional computable general equilibrium (CGE) model, for instance, TERM model (Horriidge, et al., 2011). In fact, different versions of such a model are needed to model the short run as opposed to the longer run impacts, because short run substitution elasticities are much closer to zero than their longer run equivalents, while in the long run more variables need to be determined endogenously. Such CGE models, however, are difficult and rather costly to estimate, even if the essential data, such as interregional social accounting matrices (SAMs), are available (Oosterhaven et al., 2013).

In fact, in the simpler interregional input-output (IRIO) model, the theoretical foundation to assume the fixed trade coefficients is much less relevant than the assumption of the fixed technical coefficients (Oosterhaven & Polenske, 2009). A second problem of the IRIO model is that the standard demand-driven model is only suitable to estimate the interregional, interindustry impacts of the exogenous change of the final demand in the region and industry where occurs. The impact of an exogenous change in intermediate demand may be estimated with the IRIO model. However, that requires ad hoc adjustment to prevent for double counting. In addition, the more important forward impacts of supply shocks from the region due to the disruption of the natural disaster cannot be estimated by the standard demand-driven IRIO model (Oosterhaven et al., 2013).

Unfortunately, the alternative of using the supply-driven version of the IRIO model (Bon 1988), to add an estimate of the forward impacts to the backward impacts estimated by the demand-driven version, is unacceptable for two reasons. Primarily, because both versions are fundamentally at odds with one another, implying that if the one version is a true representation of reality, the other version is false by definition (Oosterhaven, 1996). This observation has important implications for standard key sector analyses that, without much discussion, often simply add and average the multipliers from these two IO models (see Temurshoev & Oosterhaven, forthcoming, for a critical account). The second reason is that the supply-driven IO model used alone is extremely implausible in that it assumes a single homogeneous input with infinitely large demand elasticities, i.e. cars may drive without gasoline and factories may work without labour (see Oosterhaven 2012; Oosterhaven, et al., 2013, for a recent account).

The hypothetical extraction method (HEM) qualifies how much an economy’s total output would hypothetically decrease if an industry were to be ‘extracted’ from that economy. By extracting the industry, both the local purchases by the industry (i.e. backward linkages), and the local sales from the industry (i.e. forward linkages), are eliminated, or and hypothetically transformed from local purchase and sales transactions into imports and exports (Schultz, 1977). At first sight, the hypothetical extraction method (HEM) seems to be applicable to the forward impacts of supply shocks from the region due to the disruption of the natural disaster (Paelinck et al., 1965, Strassert, 1968). However, interpreting the extraction of a row of the IO matrix in the demand-driven model as measuring the forward impacts is based on the same misunderstanding as interpreting the row sum of the Leontief-inverse to represent the forward linkages of that industry (Rasmussen 1956, Oosterhaven et al. 2013).

A further restriction of the HE method is that it is only applicable to open economies, because it needs the mostly implicitly made assumption that the extraction of a row of IO matrix is fully compensated by an equally large increase in the corresponding row of the matrix with foreign imports. This restriction, the same time, represents an advantage in that implies that the HE method combines the Leontief technology assumption of fixed technical coefficients with fully flexible trade coefficients (Oosterhaven et al., 2013).

Oosterhaven (1988) uses part of these ideas in his elaborate method to measure both the supply and the demand effects of an exogenous drop in primary inputs. He uses the HE combination of fixed technical coefficients and flexible trade coefficients, but adds reciprocal technical (i.e. processing) coefficients to capture the forward impact on purchasing industries, while he allows for partial import substitution that is compensated by partial export substitution (i.e. reduction) to supply the missing inputs. The disadvantage of his method, however, is that it requires a series of case-specific assumptions that all need considerable additional information (Oosterhaven et al., 2013).

Batten (1982, chapter 5) shows how the principle of minimum information gain (cf. Theil 1967) may be used to estimate intra- and interregional trade flows in various IRIO settings. When no prior information is given, simple contingency table analysis provides a solution. The maximum entropy method (cf. Wilson 2000, chapter 6) is used when the maximum capacity of the regional transport nodes is given, while minimizing the information gain is used when a base year IRIOT is given. The latter principle is also applicable to a situation when a shock to an IRIO system results in lower production and transport capacities with an unknown new pattern of intra- and interregional trade flows. What Batten does not provide for, but what is additionally needed to model the impacts of natural disasters, is the possibility of endogenous production levels in the non-impacted industries and regions (Oosterhaven et al., 2013).

In this paper, we propose to combine the above building blocks (fixed technical coefficients, flexible trade coefficients, partial import and export substitution, and the principle of minimum information gain) in such a way that the outcome gives a reasonable estimate of the economic impacts of a natural disaster, without having to fall back of a series of case-specific assumptions or having to build a full fledge disaggregate computable general equilibrium model. In fact, we propose to build a kind of interregional input-output computable general equilibrium model that combines the simplicity of the IRIO model with the greater plausibility of the CGE approach (Oosterhaven et al., 2013).

In Section 2, we present the model. Section 3 presents the outcomes of a series of hypothetical shocks to the 2005 Japan interregional inter-industry economy as a whole, and discusses the plausibility of these outcomes. Section 4 concludes.

**2. Methodology**

We propose to measure the difference between the before and after economic situation by means of the well-known information measure of Theil (1967). Kullback (1959) first presented a measure of information gain which relies on the assumption that information is a relative quantity, and compares probabilities before and after an observation (Batten, 1983, p.28). In the application, we will study the impacts of a series of natural disasters by means of calculating the distance between the pre- and the post-disaster interregional IO table (IRIOT) for Japan in 2005.

In order to accept matrices with both positive and negative entries, GRAS approach was proposed by Junius and Oosterhaven (2003). GRAS updates IO matrices iteratively, however, the objective function of GRAS is questionable since it is biased. We use the objective function of the improved GRAS (IGRAS, Huang et al., 2008, 113-114). It is a convex function and the function value would be minimum if the target matrix is exactly equal to the original one. We use the IGRAS measure and not their comparably well performing improved normalized squared differences (INSD), because INSD treats positive and negative deviations from the base IRIOT symmetrically, whereas IGRAS puts a heavier penalty on negative deviations (Oosterhaven et al., 2013, 3-4).

In summary, we thus **minimize** the **information loss** of the post-disaster IRIOT compared to the pre-disaster IRIOT:

, (1)

where: *z* = intermediate demand, *y* = regional final demand, *e* = foreign exports, and *v* = gross value added at market prices, with *i,j* = 1, …, *I*, with *I* = number of industries, with *r* = 1, …, *R*+1, with *R* = number of regions and *R*+1 = foreign countries, with *s* = 1, …, *R*, with **·** = an index over which is summed, and with 05 = 2005 year, i.e. the actual values from the base year IRIOT. Note that the summations over the regional o***r***igin index *r* thus include a full matrix of foreign imports, whereas the summation over the regional de***s***tination index *s* excludes foreign exports. The reason for this different treatment is that IRIOTs usually aggregate foreign exports into a single column. Furthermore, note that adding the single terms with the exogenous IRIOT values just before the right hand square brackets in (1) does not influence its solution. It only secures that the minimum of (1) for the pre-disaster IRIOT is zero.

The first restriction to minimizing (1) is that all transaction **variables** are **semi-positive**, which implies that changes in stocks are excluded from the model. This exclusion is justified by the fact that changes in stocks, as a rule, do not represent economic transactions, for which we assume that economic actors try to maintain them as much as possible. Furthermore, in all scenarios we minimize (1) subject to the following additional constraints.

The second restriction is that we assume **cost minimization** under a **Walras-Leontief** production function, per input, per industry, per region, which results in (Oosterhaven 1996):

　 (2)

where additionally *x* = total output, *a* = intermediate inputs per unit of output, and *c* = value added per unit of output, with *a* and *c* being calculated from the IRIOT at hand as and. Note again that *r* runs until *R*+1, and thus includes foreign imports.

The third restriction is that we assume that the economy is in a short run equilibrium, i.e. that **demand equals supply**, per industry, per region:

. (3)

Note that the combination of the constraints (2) and (3) secures that total input equals total output for each regional industry, as +, i.e. the IO accounting identities of the IRIOT are satisfied by the non-linear program (1)-(3).

In a first test of this model with a hypothetical 2 region, 2 industry economy, it was shown that adding minimal final consumption by product by region, and, especially, also that adding a positive foreign trade balance restriction lead to less plausible outcomes (Oosterhaven et al., 2013). Therefore, here we only use the three basic constrained specified above. This means that we concentrate on the interregional and international trade changes that are likely to occur after a major disaster.

For the Japanese economy, the above-defined **base scenario**, in fact, exactly reproduces its 9X12 interregional IO table for 2005, as summarized in Table 1. This result should be considered as a *condition sine qua non* of having a plausible model.

The prime purpose of our model is to analyse the difference between the base scenario and any series of disaster scenarios. In the further plausibility tests of our model, we will make a comparison with two types of disaster scenarios that consist of solving (1)-(3) with the following constraints added:

1. A **production shock** that nullifies all output of region *r*:

(4)

This scenario may be run for each of the nine Japanese regions.

2. An **infrastructure shock** that nullifies all transport from region *r* to region *s*:

(5)

For each of the nine Japanese regions, we will define a set of interregional connections *rs* that will likely be broken in case of a disaster within region *r*.

**3.　　Empirical results**

Next to the difference in the value of (1) between the base scenario and the 2x9 disaster scenarios, analogous differences for the Japan nine regional value added totals () will be studied.

Before we do that, we first discuss the properties of the short run non-disaster equilibrium, i.e. the base scenario.

* Japanese nine regions have twelve industrial sectors in each region in 2005 Japan interregional input-output table. We aggregate the industrial sectors from twelve to three sectors in every nine Japanese regions (The 2005 Japan IRIOT, see Figure 1 and Table 1).
* Sector 1 is agriculture, forestry and fishery industry. Sector 2 is mining, manufacturing, and construction industry. Sector 3 is service industry.
* Region 3(Kanto) is the economically largest region,
* Possible re-exports of foreign imports are assumed to be zero,
* Total input equals total output for each industry, in each region.

Figure 1. The Japan nine regions of the 2005 IRIOT.



R1. Hokkaido

R2. Tohoku (Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima)

R3. Kanto (Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa, Niigata, Yamanashi, Nagano, Shizuoka)

R4. Chubu (Toyama, Ishikawa, Gifu, Aichi, Mie)

R5. Kinki (Fukui, Shiga, Kyoto, Osaka, Hyogo, Nara, Wakayama)

R6. Chugoku (Tottori, Shimane, Okayama, Hiroshima, Yamaguchi)

R7. Shikoku (Tokushima, Kagawa, Ehime, Kochi)

R8. Kyushu (Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, Kagoshima)

R9. Okinawa

Table 1. 2005 Japan interregional input-output table

Unit: Billion Yen



Table 2. Industrial sectors of Japan interregional input-output table

|  |  |
| --- | --- |
|  | Industry |
| I1 | Agriculture, forestry and fishery |
| I2 | Mining, Beverages and Foods, Metal products, Machinery, Miscellaneous manufacturing products, Construction |
| I3 | Public utilities, Commerce and transport, Finance and insurance and real estate, Information and communications, Service Industries |

The short run post-disaster equilibrium of a production shock (PS) in Region 3 (R3 Kanto) is shown in Table 3, while the shadow prices of the constraints, i.e. the marginal cost of the constraints in terms of the goal function(1), are shown in Table 4. The volume of output change due to the disruption of a production shock is only a little bit changeable in Table 3.

As for the foreign imports of intermediates goods, the volumes of post-disaster scenario due to a production shock to R3 is as about the same as the base scenario. Besides, the foreign imports of domestic final goods is as about the same as the base scenario.

And shadow prices in case of a production shock to Region3 are very small values in all sectors for each region. The volume outcomes of a production shock to other regions (R1, R2, R4, R5, R6, R7, R8, and R9) are qualitatively equal to those for R3.

Table 5 shows costs of deviation (information loss) and shadow prices in the case of the infrastructure shocks. The cost and shadow prices of the infrastructure shock (IS) to the transport links from the bigger R3 (Kanto) => smaller R2 (Tohoku) are about the same values.

As for the foreign imports of intermediates goods and domestic final goods, it is about the same value as the base scenario.

The same pattern of volume impacts is observed in case of Infra shocks of any other cases.

Table 3. The 2005 Japan IRIOT after a production shock to Region 3(Kanto)

Unit: Billion Yen



Table 4. Cost of deviation (information loss) and shadow prices in case of a production shock.



Table 5. Cost of deviation (information loss) and shadow prices in case of an infrastructure shock.



Table 6. The 2005 Japan IRIOT after an infrastructure shock to transport from Region 3(Kanto) => Region 2 (Tohoku).

Unit: Billion Yen



The pattern of volume impacts after a production shock and infrastructure shock is only a little changeable from the base scenario when we are test for the 2005 Japan IRIOT.

**4. Conclusion**

We have built a non-linear programming model that mimics the short run reactions of firms and households to a disaster in each region of the 2005 Japanese interregional input-output table. We applied the model by hitting an interregional open, nine-region, three-industry economy by nine extreme production shocks and nine infrastructure shocks.

The volume of output change due to the disruption of a production shock is only a little bit changeable in Table 3. Besides, shadow prices in case of a production shock to Region3 are very small values in all sectors for each region. The volume outcomes of a production shock to other regions (R1, R2, R4, R5, R6, R7, R8, and R9) are qualitatively equal to those for R3.

Table 5 shows costs of deviation (information loss) and shadow prices in the case of the infrastructure shocks. The cost and shadow prices of the infrastructure shock (IS) to the transport links from the bigger R3 (Kanto) => smaller R2 (Tohoku) are about the same values.

The pattern of volume impacts after a production shock and infrastructure shock is only a little changeable from the base scenario when we are test for the 2005 Japan IRIOT.

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