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Abstract

This paper develops a methodology to predict the wider interregional and interindustry economic impacts of major catastrophes, such as earthquakes and tsunamis. Short-run impacts are determined by the attempts of economic actors to continue their familiar activities and established trade patterns, as closely as possible. We propose to model these behavioural reactions by minimizing the information gain between the pre- and the post-catastrophe pattern of economic transactions in the economy at hand. The basic non-linear program reproduces the short-run equilibrium described by the base year interregional input-output table (IRIOT) of a hypothetical open, two regions, two industries economy. The proposed methodology is further tested by means of a comparison of the base scenario with two scenarios with regional production shocks and two scenarios with interregional infrastructure shocks. We conclude that the outcomes are reasonable and become more plausible when the positive foreign trade balance limitation is dropped.

Keywords: catastrophe analysis, non-linear programming, interregional input-output analysis

1. Introduction

Natural disasters, such as the recent tsunamis in Indonesia (2004) and Japan (2011), have both short run and long run negative economic impacts. These impacts occur, in not only the region and the industries directly hit by a disaster, but, due to the disruption of supply chains, also in seemingly unrelated regions and industries. These wider economic impacts are caused by the backward effect of the direct drop in demand in the region at hand and by the forward effect of the direct drop in the supply of its products. Especially in the latter case, these indirect effects may be many times larger than the direct effect, if the drop relates to the supply of irreplaceable production inputs. Besides negative impacts, there might also be short run and long run positive, regionally concentrated impacts due to inevitable reconstruction programs, while financing these programs may lead to long run negative, spatially spread macro-economic impacts.

Ideally, modelling the regional impacts of natural disasters thus requires an interregional, interindustry computable general equilibrium (CGE) model, such as the TERM model (Horridge 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 modelled endogenously. Such

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CGE models, however, are difficult and rather costly to estimate, even if the essential data, such as interregional social accounting matrices (SAMs), are available.

The much simpler interregional input-output (IRIO) model, with its point estimated zero elasticities, therefore, is often considered an alternative, especially to estimate the short run impacts. However, although the IRIO assumption of fixed technical coefficients is quite plausible, at least in the short run, that is much less the case for the additional IRIO assumption of fixed trade coefficients (see Oosterhaven & Polenske 2009). A second problem of the IRIO model is that its standard demand-driven version is only suited to estimate the interregional, interindustry impacts of the exogenous drop in *final* demand in the region and the industries hit, and that answers only part of, even the short run question. The impact of an exogenous drop in *intermediate* demand may also be estimated with the IRIO model, but that requires ad hoc provisions to avoid double counting, as intermediate demand also represents the core endogenous variable of that model. In addition, the possibly far more important forward impacts of the supply shocks from the region hit by the disaster cannot be estimated with the standard, demand-driven IRIO model.

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, for a recent account).

At first sight, the hypothetical extraction (HE) method seems to provide a way out of the impossibility to use the supply-driven IO model to capture forward impacts, in that it extracts a complete column as well as a complete row from the IO matrix (Paelinck et al. 1965, Strassert 1968, Schulz 1977). However, interpreting the extraction of a row of the IO matrix in the demand-driven IO model to represent the forward impacts of the extracted industry 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). In both cases, what is really measured are the backward impacts of the complete disappearance of the demand for an industry´s intermediate sales. It does not measure the forward impacts of the secession of these intermediate sales upon the purchasing industries.

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 (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.

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 each regional transport node 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.

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 CGE model. In fact, we propose to build a kind of IRIO CGE model that combines the simplicity of the IRIO model with the greater plausibility of the CGE approach. In Section 2, we present the model. Section 3 presents the outcomes of a series of hypothetical shocks to a small open, two regions, two industries economy, and discusses the plausibility of these outcomes. Section 4 concludes.

2. Modelling methodology

Our simulation of the short run reaction of economic actors (firms, households and various governments) to a natural disaster is based on the assumption that they attempt to re-establish the size and pattern of their economic transactions of the pre-disaster situation. We measure the distance between the situation before and after the disaster by means of the information gain measure of Kullback (1959) and Theil (1967). To mimic the adaptation strategies of all economic actors, we thus minimize the information loss of the short run post-disaster equilibrium compared to pre-disaster equilibrium of the economy at hand, i.e. the base scenario, as summarized by the interregional input-output table (IRIOT) of the nation at hand.

The information measure of Kullback and Theil, however, needs to be adapted to incorporate the criticism that arose in the discussion that unrolled after the introduction of the GRAS algorithm for updating IO matrices with both positive and negative entries (Junius and Oosterhaven 2003). Huang et al. (2008) summarize this discussion and propose an improved GRAS objective function (IGRAS). 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. The latter is desirable, as the maximum negative deviation is restricted to -100%, whereas positive deviations may be larger than +100%, while, even more importantly, having "to do" without something should be considered as much less desirable as being forced "to do" with twice as much. We furthermore prefer IGRAS, because it takes the logarithms of the relative deviations, which mimics the general economic principle of diminishing marginal returns/damages, whereas INSD squares these deviations. Finally, our version of IGRAS is a little simpler than that of Huang et al., as we do not have negative entries.

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

$$Minimize \sum\nolimits_{ij}^{rs}\left[z_{ij}^{rs}\left(\ln z_{ij}^{rs}/z_{ij}^{rs,ex}-1\right)+z_{ij}^{rs,ex}\right]+\sum\nolimits_{i}^{rs}\left[y_{i\cdot}^{rs}\left(\ln y_{i\cdot}^{rs}/y_{i\cdot}^{rs,ex}-1\right)+y_{i\cdot}^{rs,ex}\right]+$$

$$\sum\nolimits_{i}^{r}\left[e_{i}^{r}\left(\ln e_{i}^{r}/e_{i}^{r,ex}-1\right)+e_{i}^{r,ex}\right]+\sum\nolimits_{j}^{s}\left[v_{j}^{s}\left(\ln v_{j}^{s}/v_{j}^{s,ex}-1\right)+v_{j}^{s,ex}\right], \qquad (1)$$

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 *ex* = exogenous, i.e. the actual values from the base year IRIOT. Note that a summation over the regional o***r***igin index r thus includes a full matrix of foreign imports, whereas a summation over the regional de***s***tination index s excludes foreign exports. The reason for this difference in 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, while it is semi-positive for a post-disaster IRIOT.

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.

We assume **cost minimization** under a **Walras-Leontief** production function, per input, per industry, per region, which results in (Oosterhaven 1996):

$$\sum\nolimits^{r} z_{ij}^{rs} = a_{ij}^{\cdot s}\, x_{j}^{s} \ and \ v_{j}^{s} = c_{j}^{s}\, x_{j}^{s}, \forall i, j, s, \qquad (2)$$

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 $a_{ij}^{\cdot s} = \sum^{r} z_{ij}^{rs,ex} / x_{j}^{s,ex}$ and $c_{j}^{s} = v_{j}^{s,ex} / x_{j}^{s,ex}$. Note again that r runs up till R+1, and thus includes foreign imports.

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

$$\sum\nolimits_{j}^{s} z_{ij}^{rs} + \sum\nolimits^{s} y_{i\cdot}^{rs} + e_{i}^{r} = x_{i}^{r}, \forall i, r. \qquad (3)$$

Note that the combination of the constraints (2) and (3) secures that total input equals total output for each regional industry, as $a_{\cdot j}^{\cdot s} + c_j^s = 1, \forall j, s$, i.e. the IO accounting identities of the IRIOT are satisfied by the non-linear program (1)-(3).

We further assume that consumption is maintained above a **minimal final consumption**, per product, per region:

$$\sum^r y_{i\cdot}^{rs} \geq \sum^r y_{i\cdot}^{rs,ex}, \forall i, s. \tag{4}$$

Note that (4) applies per product irrespective of the regional origin of that product. Thus, (4) represents a kind of Walras-Leontief technology restriction for final consumption.

Finally, we assume that international trade is constrained by a **positive foreign trade balance**:

$$\sum_i^r e_i^r - \sum_{ij}^s z_{ij}^{ms} - \sum_i^s y_{i\cdot}^{ms} \geq 0. \tag{5}$$

Note that adding the semi-positive national foreign trade balance (5), by definition of the gross domestic product (GDP), implies that national savings are semi-positive too, i.e. that $v_{\cdot}^{\cdot} - y_{\cdot\cdot}^{\cdot\cdot} \geq 0$.

For our hypothetical economy, the above-defined **base scenario**, in fact, exactly reproduces the 4x4 hypothetical interregional IO table used in the sensitivity analysis (see 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)-(5) with the following constraints added:

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

$$\sum_i x_i^r = 0 \tag{6}$$

This scenario is run for each of the two hypothetical Regions 1 and 2. It, of course, represents two extreme scenarios. In reality, a production shock due to even a major disaster is likely to only partially diminish the production capacity of only a subset of the industries. For testing the plausibility of our modelling approach, however, using an extreme scenario will give a clearer outcome than simulating a more realistic, i.e. less extreme, scenario.

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

$$\sum_{ij} \left(z_{ij}^{rs} + y_{i\cdot}^{rs} \right) = 0 \tag{7}$$

This scenario is run for the two hypothetical transport links, namely 1 => 2 and 2 => 1. Again, two extreme cases are taken to test our model. In reality, an infrastructure shock will never be as total as we assume here. On the other hand, however, in reality it will most likely be two-directional, and not one-directional as assumed here. Here too, this choice is made to get clearer outcomes.

Next, we discuss the plausibility of the estimated consequences of the, above defined, production and infrastructure shocks, and whether, on the basis of that, our model needs to be changed or not.

3. Modelling outcomes

Before we do that, we first discuss the properties of the short run non-disaster equilibrium, i.e. the base scenario. The hypothetical two regions, two industries IRIOT that represents this equilibrium is constructed such that it has the following properties (see Table 1):

- Region 2 (say core) is economically larger than Region 1 (say periphery),
- Region 2 has net savings (88 + 134 – 184 = +38), while R1 is a net borrower (56 + 58 – 150 = -36),
- Industry 2 (say services) is economically larger than Industry 1 (say commodities),
- The foreign trade balance is positive (168 – 166 = +2), and thus value added exceeds local consumption, i.e. national savings (336 – 334 = +2) are invested abroad,
- Possible re-exports of foreign imports are assumed to be zero,
- Production of government and household services is included in Industry 2, i.e. value added of local consumption is zero, and, of course,
- Total input equals total output for each industry, in each region.

Table 1. Hypothetical, two region and two industry, input-output table.

	Region 1		Region 2		Local consumption		Foreign	
	I1	I2	I1	I2	Region 1	Region 2	exports	Total
Region 1, Industry 1	15	10	5	4	25	15	26	100
Region 1, Industry 2	11	30	9	7	45	14	34	150
Region 2, Industry 1	5	8	35	34	22	55	41	200
Region 2, Industry 2	6	14	38	35	27	63	67	250
Foreign imports, I1	4	13	16	20	18	28	0	99
Foreign imports, I2	3	17	9	16	13	9	0	67
Value added	56	58	88	134	0	0	0	336
Total	100	150	200	250	150	184	168	
Additional totals		*Foreign imports*		*166*		*Local consumption*		*334*

The short run post-disaster equilibrium of a complete production stop in Region 2 (R2) is shown in Table 2, 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 outcomes of a production shock to Region 1 (R1) are qualitatively equal to those for R2, i.e. comparable changes have the same signs, which is why we do not show and discuss them here.[2]

[2] All disaster scenarios are solved by means of the *fmincon* function with the *interior-point* algorithm from Matlab 2013a. Each non-linear disaster program is solved within 4,000 evaluations.

Table 2. Hypothetical IRIOT after a production shock to Region 2.

	Region 1		Region 2		Local consumption		Foreign	
	I1	I2	I1	I2	Region 1	Region 2	exports	Total
Region 1, Industry 1	72.9	57.1	0.0	0.0	53.1	62.1	83.6	328.7
Region 1, Industry 2	57.8	122.9	0.0	0.0	74.2	65.1	67.7	387.7
Region 2, Industry 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 2, Industry 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Foreign imports, I1	6.0	23.1	0.0	0.0	11.9	35.9		76.9
Foreign imports, I2	7.9	34.8	0.0	0.0	10.8	20.9		74.4
Value added	184.1	149.9	0.0	0.0				334.0
Total	328.7	387.7	0.0	0.0	150.0	184.0	151.3	
Additional totals		Foreign imports		151.3		Local consumption		334.0

At first sight, the cross type of pattern of the zeros in Table 2 exactly equals the result of applying the hypothetical extraction (HE) method to R2 (cf. Dietzenbacher et al. 1993, Sonis & Oosterhaven 1996). Closer inspection, however, shows that the non-disaster economy of R1 does not shrink, as with the HE method, but grows to compensate for the loss of production in R2, and that is of course precisely what would happen in reality. Thus, on this count, our approach produces far more plausible outcomes than the HE method.

Not in contrast, but comparable to the HE method, our model also predicts a growth of foreign imports of intermediates by R1´s industries to compensate for the loss of domestic intermediate imports from R2. In fact, with our model the increase in foreign intermediate imports is larger than with the HE method, as the larger output of the non-disaster R1 requires more intermediate inputs than the shrunken output of R1 in case of the HE method.

As to the foreign imports of final goods, which are exogenous in the HE method, our model predicts that those into the disaster R2 will increase. That is quite reasonable, along with the increase in the domestic final imports from R1 into R2, which are also exogenous in the HE method, as both together have to compensate for the loss of R2´s own final output. This outcome is again more plausible than the HE outcome, where nothing changes, except for the zero final output of R2´s industries.

The final imports into the non-disaster R1, however, decrease considerable, such that the aggregate foreign imports even show a small decrease. We consider this result as the only outcome that is less plausible. To explain it, first note that the foreign trade surplus of 2, say billion, in the pre-disaster Table 1 reduces to zero in the post-disaster Table 2, which is reflected in the positive shadow price of the foreign trade restriction (see the last row of Table 4).

Next, note that requiring the national foreign trade balance to be positive is equivalent to requiring national savings to be positive, while the latter is equivalent with requiring value added to be larger than local consumption. Since, local consumption by product is required to exceed its pre-disaster values because of restriction (3), total value added is required to exceed the pre-disaster value of total consumption of 334 billion. In Table 1 this is the case, and precisely this 2 billion surplus is the maximum with which national value added may decrease, and in fact also decreases.

Consequently, because of the Leontief technology requirements of equation (2), total national output and total national intermediate input may only decrease by a little too. Hence, total output of the non-disaster R1 has to compensate for the fall in total output in the disaster R2. This last conclusion directly explains why our model results in a reduction of both aggregate foreign imports and aggregate foreign exports in the case of the two production shocks.

Hence, dropping the foreign trade restriction (5), most likely, will lead to outcomes that are more plausible. This is confirmed in Table 3, which shows the short run post-disaster equilibrium without imposing a semi-positive foreign trade balance, i.e. it shows the solution of solving the non-linear program of (1)-(4) with (6) for R2. The volume outcomes of solving (1)-(4) with (6) for R1 are again qualitatively equal, which is why they are not shown and discussed here either.

Table 3. Hypothetical IRIOT after a production shock to Region 2, with flexible foreign trade.

	Region 1		Region 2		Local consumption		Foreign exports	Total
	I1	I2	I1	I2	Region 1	Region 2		
Region 1, Industry 1	19.0	12.7	0.0	0.0	32.2	26.9	18.4	109.1
Region 1, Industry 2	15.2	37.5	0.0	0.0	58.3	42.6	21.5	175.2
Region 2, Industry 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Region 2, Industry 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Foreign imports, I1	7.2	23.5	0.0	0.0	32.8	71.1		134.6
Foreign imports, I2	6.6	33.7	0.0	0.0	26.7	43.4		110.4
Value added	61.1	67.7	0.0	0.0				128.8
Total	109.1	175.2	0.0	0.0	150.0	184.0	39.8	
Additional totals		Foreign imports		245.0		Local consumption		334.0

Just like Table 2, Table 3 also shows the HE cross with zeros for R2, and the increases in output, and intra-regional and foreign intermediate inputs of R1. And just like Table 2, it also shows increases in the domestic final sales of industries of R1 to compensate for the lost final sales from the R2. The decrease of foreign final imports into R1 in Table 2, however, changes into an increase in Table 3, which is more plausible, while all other increases in foreign imports in Table 3 are larger than in Table 2. Consequently, now, total foreign imports increase instead of decrease, which is a much more plausible outcome.

Furthermore, the foreign exports of R1, now, show a decrease instead of an increase. Without the foreign trade restriction, the home market of the disaster R2 is served first. This implies that Table 3 now exhibits both partial import and partial export substitution, whereas the latter was absent in Table 2 compared to Table 1. This outcome is more plausible too.

The only possible critique on the outcomes of Table 3 is that the resulting national trade deficit is rather large. As a short run reaction to a natural disaster, that outcome is possible, but it is also clear that such a huge deficit is not sustainable in the somewhat longer run than a single year.

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

	Production Shock to R1		Production Shock to R2	
	With (5)	Without (5)	With (5)	Without (5)
Value of objective function	544	469	1323	871
Supply = demand for R1, I1	5.5E+10	4.5E+12	2.6	0.3
Supply = demand for R1, I2	5.5E+10	4.5E+12	3.1	0.5
Supply = demand for R2, I1	1.1	0.2	2.8E+11	8.1E+10
Supply = demand for R2, I2	1.0	0.2	2.8E+11	8.1E+10
Min. local consumption for R1, I1	1.7	0.6	3.4	0.6
Min. local consumption for R1, I2	1.9	0.9	3.6	0.7
Min. local consumption for R2, I1	1.4	0.3	4.0	0.9
Min. local consumption for R2, I2	1.2	0.3	4.6	1.6
Positive foreign trade balance	1.4		3.8	

Table 4 shows cost of the deviation from the pre-disaster equilibrium and the shadow prices of the constraints in case of the two production shock (PS) scenarios; both with and without the foreign trade restriction (5). As might be expected, a one unit smaller PS, i.e. marginally releasing restriction (6) and thus also restriction (3), produces by far the largest reduction in the deviation from the short run equilibrium, as is shown by the shadow prices with E+10, E+11 and E+12.

Furthermore, observe that the value of the objective function and all shadow prices of a PS to R2 are about twice larger than those of a PS to R1. This is not surprising either as R1 was constructed in such a way that it is economically about two times smaller than R2, and thus one would expect that a disaster to this much smaller region would hit the national economy less than a disaster in its economic core. Moreover, note that the objective function and all shadow prices of both PS´s are smaller when the positive net foreign trade requirement is lifted,[3] which means that the cost of adaptation after the disaster is smaller when foreign aid (i.e. a trade deficit) is accepted without restriction.

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

	Infra Shock to R1 => R2		Infra Shock to R2 => R1	
	With (5)	Without (5)	With (5)	Without (5)
Value of objective function	66	65	115	112
Supply = demand for R1, I1	-0.1	-0.2	0.4	0.2
Supply = demand for R1, I2	-0.1	-0.2	0.5	0.3
Supply = demand for R2, I1	0.2	0.1	0.0	-0.2
Supply = demand for R2, I2	0.2	0.1	0.0	-0.2
Min. local consumption for R1, I1	0.0	0.0	0.8	0.5
Min. local consumption for R1, I2	0.0	0.0	0.8	0.6
Min. local consumption for R2, I1	0.3	0.2	0.1	0.0
Min. local consumption for R2, I2	0.4	0.3	0.1	0.0
Positive foreign trade balance	0.1		0.3	

[3] The exceptions are the two 4.5E+12 shadow prices of a PS to R1 in absence of the foreign trade restriction.

Table 5 shows the same information as Table 4 in case of the two infrastructure shocks (IS) of equation (7), again with and without the foreign trade restriction (5). In this case dropping this restriction hardly makes a difference, as each infrastructure shock only affects interregional trade in one direction, while leaving regional production capacities intact. The latter also explains why the extreme shadow prices of the production constraints in Table 4 disappear in Table 5.

Again the cost and the shadow prices of the IS to the transport links from the bigger R2 => smaller R1 are about twice as big as those for the IS to the links from the smaller R1 => bigger R2. When the IS is to R1 => R2, production in R2 has to rise to fill the gap, and thus satisfying local consumption of R2 becomes more of a constraint. Consequently, in that case, these two sets of shadow prices are far larger for R2 than for R1. Analogously, the shadow prices of the consumption constraints for R1 are larger than those for R2 in case the IS to R2 => R1.

Especially interesting are the negative shadow prices for production. Take the case of the IS to R1 => R2. Not being able to export to R2 makes part of the production in R1 redundant. The foreign exports of R1 will increase but obviously not enough to compensate for the loss of the domestic exports to the large R2. This expectation is confirmed in Table 6, which shows the volume impacts of an IS to all transport from R1 => R2. The production levels in R1 stay below their pre-disaster levels, notwithstanding that its foreign exports as well as its intra-regional sales to Industry 2 and to local consumers in R1 all increase. Since the industries of R2 and foreign imports have to fill the gap that results from the loss of imports from R1 => R2, their volumes increase as expected.

Table 6. Hypothetical IRIOT after an infrastructure shock to transport from Region 1 => Region 2.

	Region 1		Region 2		Local consumption		Foreign	
	I1	I2	I1	I2	Region 1	Region 2	exports	Total
Region 1, Industry 1	14.7	10.7	0.0	0.0	29.7	0.0	33.6	88.7
Region 1, Industry 2	10.9	30.1	0.0	0.0	50.4	0.0	42.5	133.9
Region 2, Industry 1	3.5	6.2	38.8	37.6	18.8	63.3	38.2	206.4
Region 2, Industry 2	4.5	10.7	46.3	41.5	23.0	74.8	63.8	264.5
Foreign imports, I1	3.0	10.8	19.0	23.8	16.5	34.7		107.8
Foreign imports, I2	2.4	13.6	11.5	19.9	11.6	11.2		70.3
Value added	49.7	51.8	90.8	141.8				334.0
Total	88.7	133.9	206.4	264.5	150.0	184.0	178.1	
Additional totals		Foreign imports		178.1		Local consumption		334.0

The main outcome of Table 6 that is not directly according to our expectation is the decrease in the intra-regional purchases of Industry 1 (I1) in R1. Looking closer into this outcome reveals that the intra-regional import ratios, i.e. the self-sufficiency ratios, of Industry 1 in R1 do increase as expected. The drop in the output level of I1 in R1, however, is relatively larger, such that the net effect on the intra-regional intermediate demand of I1 in R1 is negative.

The same pattern of volume impacts is observed in case of an IS to R2 => R1, which for that reason is not shown here. The only qualitative difference with Table 6 is that now the negative output effects in R2 are relatively smaller than the positive impact on its self-sufficiency ratios, and consequently both industries in R2 end up consuming more local intermediate inputs, instead of less, which was the case for I1 in R1 in Table 6.

Table 7. Hypothetical IRIOT after an IS to transport from R1 => R2, with flexible foreign trade.

	Region 1		Region 2		Local consumption		Foreign	
	I1	I2	I1	I2	Region 1	Region 2	exports	Total
Region 1, Industry 1	14.1	10.2	0.0	0.0	30.2	0.0	31.4	85.9
Region 1, Industry 2	10.4	29.2	0.0	0.0	52.7	0.0	39.8	132.1
Region 2, Industry 1	3.4	6.0	36.9	35.8	19.4	62.2	36.2	200.0
Region 2, Industry 2	4.3	10.4	44.3	39.5	24.2	74.2	60.0	256.9
Foreign imports, I1	3.1	11.0	19.1	23.8	18.0	35.8		110.9
Foreign imports, I2	2.4	14.1	11.7	20.1	13.0	11.8		73.2
Value added	48.1	51.1	88.0	137.7				324.9
Total	85.9	132.1	200.0	256.9	157.5	184.0	167.5	
Additional totals		Foreign imports		184.1		Local consumption		341.5

Table 7 shows the volume impacts of the IS to R1 => R2 without restricting foreign trade. Quantitatively, the results are quite comparable to those of Table 6, as was already clear from the shadow prices in Table 5. Qualitatively, however, they are different, especially of course for foreign trade. Foreign imports and exports are equally large in Table 6, whereas the imports exceed the exports in Table 7, but with much less than with the production shock to R2 in Table 3. Moreover, we observe that local consumption exceeds its minimum, which is also evident from the zero shadow prices for local consumption in Table 5. The main reason is that, not being able to export of R2, the industries in R1 are selling more to their local consumers.

In all, we conclude that the outcomes of the model without the foreign trade restriction (5) are more plausible, be it that the difference is much smaller in case of the infrastructure shocks than in the case of the more extreme production shocks.

4. Conclusion

We have built a non-linear programming model that mimics the short run reactions of firms and households to a disaster in a specific region. We tested the model by hitting a hypothetical open, two regions, two industries economy by two extreme production shocks and two one-directional infrastructure shocks. These tests showed that imposing positive net foreign trade leads to less plausible results than lifting that restriction, which is the right thing to do when modelling short run impacts. Theoretically, we concluded that modelling long run reactions anyhow requires a different approach. The outcomes of our short run simulations, without the net foreign trade restriction, are considered quite reasonable, because they show a plausible mix of both domestic and foreign import and export substitution in reaction to the losses of production and transport capacities.

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