Thinking about Big Floods in a Small Country: Dutch Modelling Exercises[1]

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Abstract

In this contribution we discuss new developments in Dutch thinking about the increasing risk of big floods. A first issue concerns the choice of methodology. Today several ones exist to assess the consequences of big natural catastrophes, differing significantly in background philosophy, objective or scope. It is questionable whether market-based approaches that are dominant in the U.S. are fruitful for a small country with a large state influence, such as the Netherlands. Probably it is better to start from the notion of specific types of network disruptions in a highly developed and densely populated country.

In this paper, we focus on the interdependencies between production and consumption activities. This leads to an investigation based on Input-Output (I-O) methodologies. A big flood then causes a series of disruptions in the existing production and consumption networks. Our paper addresses the point that I-O as it stands is not very appropriate. The basic problem is that I-O models stress interaction and equilibrium, while here we have to deal with disruption and disequilibrium. This means that the economy suddenly has to decide on the way its now restricted resources should be distributed.

Our research is based on the basic hypothesis underlying I-O models, i.e. the need to distinguish between two major categories of destination, 'final consumption', and 'intermediate demand'. Outcomes will be different according to the choices being made. One reason is the presence of multiplier effects, which reflect current interactions. A choice in favour of final demand will alleviate problems of the affected groups, but at the same time will increase inter-industry imbalances, and imply a heavy role for supporting import. In fact, a major decision is asked for. Economic policy needs to steer the distribution of the available goods in intelligent ways between various categories of buyers and suppliers. The choice is not straightforward, and involves complex interrelations and interactions.

Key words: floods, disaster consequences, economic network, disequilibrium, input-output.

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[1] Preliminary version, please do not quote without the permission of the authors.

1. Introduction

The recent tsunami of the second Christmas day (26 Dec 2004) shook the whole world. The strong earthquake underneath the sea has caused powerful waves bringing devastations thousands kilometers away from the epicenter. This outrageous event cost around 280 000 lives. The disaster took millions of people by surprise – nothing of such scale was expected. In the immediate aftermath of the event a number of questions were asked: Was it possible to forecast the disaster? Was it possible to prevent the damage? And what can be done to be aware of such calamities in the future?

In this recent catastrophe in Asia most of damage was caused to private housing and human life, without major loss of industrial capacity (probably except for coastal fishing and tourism sectors) opposite to what can be expected in the case of disaster in a developed economy, where probably industrial loos would dominate the picture. However the effects might be different, the questions asked are all the same. In this paper we are looking at the major distortions brought about by a calamity into a functioning industrial system with a particular focus on the economic consequences.

In the Netherlands, the low-laying country with the complex system of dikes, the matter of a natural disaster has always been the topic of study. The country has the highest population density in Europe (474 pers./km^2 against the EU(15) average of 120 pers./km^2 in 2001[2]), and highly developed industrial production, with the state taking active role in the economic activity regulation. Especially in the course of the 20th century the growth of industrial activity has lead to the accumulation of the economic assets within the dike rings. At the same time, the rising sea level puts more pressure on the coast protection and the more frequent precipitation calls for better protection from the high water in the rivers. This situation asks for more attention with respect to the issue of a vast flooding and its consequences for the entire economy.

What does actually a disaster mean? Extreme adverse events like a major flooding in Holland may cause a loss of parts of the economic system, temporary or forever (a sort of network failure). This in fact means that the established economic structure experiences a shock –

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[2] Source: Eurostat website http://europa.eu.int/comm/eurostat/newcronos/reference/display.do?screen=welcomeref&open=/popul/Popula/main/demo-r/poparea&language=en&product=EU_population_social_conditions&root=EU_population_social_conditions&scrollto=227

the disruption that is so significant that some economic ties brake. This suddenly puts the economy in the position of disequilibrium. In such a situation, how does the system adjust? Is the new structure under way? Will it mimic the old one or a new one will emerge?

One of the critical features of natural disasters that we just have to take for granted is their nearly unpredictability. In most cases, people get (if any) a short notice before the event happens. This puts us in the position of being ‘always ready’ for the unexpected. Thus, in this paper we will especially concentrate on the ways one may think about the recovery after a disaster.

The literature on natural disasters, and in particular the studies covering economic cost assessment part, is extensive. Several scientific research centres have devoted their efforts to investigate this field. A substantial part of the literature concerns the economic dimension of natural disasters and their consequences. A certain dominance of authors from the US and Japan is observed (Cole, Pantoja et al. 1993; Cochrane 1997; Jones 1997; Rose and Benavides 1998; Shinozuka, Rose et al. 1998; Okuyama, Hewings et al. 2002; Cole 2003; Cole 2004) mostly concentrating on the issue of earthquakes, although also contributions from European research should be mentioned (among others, (Parker, Green et al. 1987; van der Veen, Vetere Arellano et al. 2003)), contributing flooding issues to the field.

In this paper we concentrate on the methodological aspect in disaster analysis within the I-O framework. We suggest that a two-step procedure is involved. The starting point of our approach is how to model in a systematic way the immediate effects of a catastrophe. We target at the methodologically consistent model in response to current studies, mostly applied. This results in a kind of bookkeeping accounts, which, however, do not reflect the feasible economic interactions. So, we need a second step to extract information regarding the economic structure from these ‘bookkeeping’ operations. Only hereafter stage two with the construction of recovery processes may be followed. Finally, some recovery paths are analysed in the longer run perspective provided government policy objectives. The resulting approach should probably be seen as the read-map for direct effect accounting in the effort of putting numerous research work on one plane, and serves a starting point for the recovery modelling. In this paper we will not go as far as what might be called a full operationalisation of the required concepts. Rather, this paper should be viewed as providing a set of building blocks for later work.

Our paper is organised as follows. In Section 2 and 3 we shall start with some background, discussing the major aspects in search for common grounds in input-output analysis type of research. Section 4 puts forth the modified I-O model, which will be our point of departure. Hereafter, we introduce what may be called the 'Basic Equation'. In Section 5 we fill the 'Basic Equation' with a number of assumptions to illustrate how a real I-O system can be subtracted from it based on the particular government objectives. We round it up with the proposal about the construction of an Event Matrix. We leave nevertheless more detailed implications on these findings for further examination. Section 6 closes with the conclusions.

2. The Input-Output: Why?

In this paper we are focusing on the methodology for major shock analysis. We are basing our exploration on the case of a major flooding in the Netherlands as a reference point. For some background of our previous research, see (van der Veen and C.J.J.Logtmeijer 2003; Bočkarjova, Steenge et al. 2004; Bočkarjova, Steenge et al. 2004; Bočkarjova, Steenge et al. 2005).

Let's first settle the definition of a disaster. Following ISDR[3], a disaster is "a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources." This means, that a natural hazard[4] becomes a disaster only when the interaction between the nature and the socio-economic structure as a result of a human activity has taken place. Further, the definition is extended (ibid): "A disaster is a function of the risk process. It results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk." This second part of the disaster definition is of our major interest here. Because the definition is based on the notion of risk, it should be in place to comment on that as well. Risk is the product of probability of an event to happen and the costs connected to this event. Therefore, the scale of a disaster depends first of all on the nature of the hazard and the second on damage that is incurred by it. It is important to mention that the last decades have shown the rising awareness about the

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[3] See http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm

[4] Hazard is sometimes interchangeably used with disaster, however a hazard is "potentially damaging physical event, phenomenon or human activity that *may cause* the loss of life or injury, property damage, social and economic disruption or environmental degradation", (ISDR). A disaster is a realised hazard.

increasing concentrations of 'greenhouse' gases in the atmosphere, which are presumed to cause the climate change. It is currently identified by the global average warming and (as pointed out by some experts, see (IPCC 2001), p.72) by the increase in the number and severity of extreme weather events, increased precipitation and the sea level rise. However, taken the scope of this paper, we will assume that man cannot influence the probability of emergence of hazard which we assume increasing taking into account the climate change argument. Instead, we will seriously consider here the costs side a hazard may cause.

Different models are used for the economic analysis of vast disasters, like CGE, micro-simulations, and extensively input-output (I-O), which is appreciated for its merits. In the U.S., for example, several market-based approaches have been presented recently, focusing on short run disequilibria. Certain preferences seem to exist, depending on country and type of catastrophe we wish to study. Nonetheless, by and large the debate is still open, depending on what the country or region views as its major problem. In a pure market economy decisions made most likely will be different from those made in a heavily regulated country like the Netherlands.

When choosing a model for the research of a particular phenomenon, one should inevitably make choices between complexity and flexibility on the one side and simplicity, rigidity and transparency on the other side, while targeting the reliability and coherency. In this sense, input-output can be scaled as a transparent model, though in a sense rigid, but in its simplicity reflecting the whole network of economic ties in the country (region, etc. depending on the scale of research). In this paper we would like to extend I-O model's flexibility especially with respect to the large-scale shock analysis (as the model is primarily designed for marginal policy analysis), keeping in line with its coherency and reliability. In our contribution, we model the consequences of a disaster where a part of the existing economic networks fails temporarily or forever. Several situations can be distinguished: after the disaster, many suppliers will have lost their customers. Vice versa, it also may be impossible to satisfy existing demand because the supplying firms cannot deliver any more.

For the estimation of economic loss many authors start from the basic input-output (I-O) model developed by Wassily Leontief in the 1930s and 40's (Leontief 1986).The basis for Input-Output model is the table of inter-industry transactions - sales and purchases - reflecting the structure of the economy. The table is based on the idea of balances – each sector's expenditures should equal the income that it is earning. The model has seen a number of revisions and extensions (see e.g. (Miller and Blair 1985) for an introduction in methodology and method). The production processes and inter-industrial relations have undergone extensive reconsideration, as well as the selection of the major players, such as the government, consumers and the external parties. Nonetheless, in essence it has remained the same, the basic framework does not seem to have changed much. Particularly, considerable problems emerge if we apply the model for the study of a major disruption in the network. This, in a sense, is a pity. We now are forced to adopt perhaps a rigid straightjacket for modelling what is happening in the real world. At the same time, it also opens new opportunities to resolve the rigidity dilemma. How do we model a dislocated network? How do we come to a new and consistent I-O model? In this paper we will try to profit from this challenge and offer a new way of the large-scale shock modelling.

I-O is particularly useful in studying the flow of goods and services. It allows us to distinguish various types of direct and indirect effects, based on extensions of accepted multiplier analysis. However, there remain several aspects that are not fully covered yet. In this paper we shall point out that the basic theoretical framework in fact is quite *flexible* and after some modifications allows us to focus directly on the issues at stake. We suggest looking at the fundamentals trying to inject specific dynamics in what basically looks like a rather static framework. Our approach generates its own data needs, and it will rather be data availability, accuracy, and so on, that determine which result ultimately will be within reach.

A lot of valuable work has so far been done in the field. However much of it is rested on the particular empirical needs (Shinozuka, Rose et al. 1998) and / or serves practically defined purposes (Tierney and Nigg 1995; Freeman, Martin et al. 2004). Thus, the nature of such work often forces the researcher to develop specific methods for the case-oriented problems, and ad-hoc approaches are being made use of, while theoretical and methodological aspects had stayed for a while out of sight. In this respect, we will propose a more general position. This generalised approach may hopefully provide a connecting bridge between empirical application of the model and its theoretical foundation. However, in this paper we will take a more conceptual standpoint, discussing the philosophy behind the model.

3. Disaster Analysis within I-O: Looking for a Starting Point

As far as we are concerned here with a large-scale devastation brought by disasters, we should realise that this brings about also serious alterations in the entire economy. Therefore, marginal analysis is of no use here. At the same time, it is absolutely important to trace this major metamorphose. Nevertheless, the reviewed literature suggests that methodologically speaking the ‘starting points’ for the I-O type of analysis are scattered, though it is recognised that it is crucial for the whole process of modelling to understand what exactly is happening *immediately after* the disaster. The literature ascertains that there is a great need for a good understanding of the post-disaster situation. (Okuyama 2004), p.125, e.g., points to the uncertainty that appears as a result of a disaster:

> “Uncertainty arises after a disaster because first, the extent and range of direct damages are unknown right after the event; second, the trends of economic activities, especially the fluctuation of demand, become unclear in the short run; and third, the influx of demand injections for recovery and reconstruction activities makes the long-run forecast of economic growth in the region difficult. …on the other hand, the degree of uncertainty over time requires a careful treatment.”

That’s why we would first like to focus precisely on that issue in this paper. In this context, we suggest to “put on new glasses” and discover new features of the I-O model. We would also like to make a connection to the notion known in the literature as an “event matrix”.

In this paper we shall address necessary background for the notion of an ‘Event Matrix’ to structure the modelling of a shock. In the literature dealing with the economic consequences of a natural catastrophe the notion of an ‘Event Matrix’ is used to introduce system into our thinking about the impacts of an exogenous event on the I-O system. That is, this special type of matrix helps us study the effects of a catastrophe until the time horizon set for analysis. However, the foundation of the concept of an Event Matrix needs additional support. Probably (Cole, Pantoja et al. 1993), p.4-7) was the first to introduce the notion of an Event Matrix:

> “In the most general case, the event matrix will be a set of tables corresponding to entries in the original IO table which specifies i) the extent of damage to internal and external components, ii) the goal for recovery and iii) the time scale for recovery. The details [of how an event matrix is specified] will depend on the situation under investigation.”

Our concern then is contributing to the precision of the notion of an Event Matrix. In order to specify our point of view in particular, we would like to 'split' the elements of the definition above given by (Cole, Pantoja et al. 1993) into two stages: stage one would encompass element i), while stage two would consist of the elements ii) and iii). This will allow us to operate within a two-step procedure framework. In this contribution we shall focus on the first stage, as well as provide some insights about modeling possibilities for the second stage.

As a result of a disaster the existing ties within an economy are seriously disrupted. This implies that we have to think in novel ways about the current notions of equilibrium and disequilibrium. Thus, in our view, stage one should form *the basis for systematic accounting* for the actual physical damage brought by a disaster. This means that we first make a (summary) statement on what is left after an outbreak of a catastrophe. The way an economy reacts after a disaster basically depends on three sets of factors: the level and severity of the damage incurred, the economy's resilience[5], and the external factors. (Cochrane 1997)b, pp.243-244) points out that combinations of these broadly defined factors stipulate the gains and losses ratio of a shock brought by a disaster and thus identify the recovery path of each particular economy towards a (new) equilibrium. Also (Rose and Lim 2002) discuss a similar issue (p.12): "More sectorally diverse economies are better able to withstand the shocks of business interruption losses".

The literature (Okuyama 2003; van der Veen, A.E.Steenge et al. 2003; Cochrane 2004; Rose 2004) seems to agree that a precise *theoretical* starting point for disaster research is often missing. Even where it is assumed 'obvious', the basic issues of disaster implications always seem to require some additional attention. For example, there is no accepted formula for representation of disrupted ties within an I-O table as a result of disaster. We will focus therefore on the way the I-O modelling framework can help us in analysing the immediate effects of a catastrophe.

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[5] See for the explicit discussion of resilience, vulnerability and related notions, e.g.: Green, C. (2003). Evaluating Vulnerability And Resilience In Flood Management. Joint NEDIES and University of Twente Workshop In search of a common methodology for damage estimation. A. van der Veen, A. L. Vetere Arellano and J.-P. Nordvik. Delft, the Netherlands, Office for Official Publications of the European Communities. **EUR 20997 EN:** 19-52.)

4. The Derivation of an After-Shock Equation

The approach to the extension of the I-O model presented here is novel. We start with the short description of the basic framework introduced in (Bočkarjova, Steenge et al. 2004)a,b. It is important to gain a grasp over that presented method as it will form the backbone for the recovery modelling (second stage) that we intend to discuss in the following sections.

We mentioned that a well-founded theoretical point of departure is of prime importance in disaster research. But if we are trying to employ the I-O framework for analytical purposes, we immediately run into a major problem. I-O essentially is based on the concept of sectoral balances embedded in a circular flow. At present, we do not have a well-accepted theory of what happens if specific parts of this circular flow suddenly malfunction. However, the existing theoretical framework offers possibilities that have not been explored up to now. Below we shall propose a way to make a head start in modelling the phase immediately after the disaster in an I-O context. In the following sections, we shall focus on the question how those parts of the economy that are still intact will adapt to the new circumstances.

As we know, in an I-O table only the part of the inter-industry flows that deals with production is represented in terms of fixed coefficients[6]. In a normal situation a firm sells part of its product to other manufacturers and part of it to the final users. The proportions between these parts are the result of many factors, some technical, some institutional, and some traditional. It is not easy to say what will happen if a particular firm is confronted with the fact that *some* of its customers (or suppliers) are not there anymore. Thinking about such cases will have to be based on the relevant behavioural, historical and technical circumstances, in the light of the possibilities that remain after the disaster.

For this reason, it is advisable to adopt a modelling framework that seems flexible enough to face such choices. Clearly, many issues are involved. Let us now first take a look at the standard open I-O model, and let us see if this is a suitable candidate for a good starting point. We have:

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[6] That is, in the A^0 coefficients table only the vertical entries are fixed in proportions, the horizontal are not (see further Miller and Blair, 1985)

$$x^0 = A^0 x^0 + f^0, \qquad [1]$$

where x^0, f^0 and A^0 respectively stand for total output, final demand and the matrix of input coefficients in the initial situation before the flood. Let's also introduce the labour market. It plays an essential role in shock analysis, because disturbances in labour markets may be a prime cause of long-term delays in economic growth. Therefore, we shall try to find a way to incorporate its volatilities and effects into our model. Standard, we have:

$$L^0 = l^0 x^0 \qquad [2]$$

Here L^0 represents the scalar of overall labour supply and l^0 the vector of direct labour input coefficients in the situation before the flood[7].

If a disaster strikes, this will, above all, affect the production levels x^0. However, via disturbances in x^0 also the sectoral demands for labour will be affected. A shift in these labour demands immediately will translate into a shift in final demand f^0. Therefore, we have to select a framework that allows us to address these points appropriately. The same is true when we would have started with a change in labour availability. Evidently, substitution and adaptation of production processes must follow. Therefore, we have to work out a strategy to incorporate such effects in a flexible, simple and direct way in the I-O framework. Though I-O often is considered as a rather rigid model in terms of its assumptions, we shall venture some steps along this road, while adhering strictly to the rules.

We now shall try to reconstruct the state of affairs in the economy, directly after a flood, on the basis of those parts that are *not* directly damaged and, in principal, remain active. In line with this we propose the following. We shall assume that a reduction in the sector's labour input requirement directly translates into a corresponding reduction in final demand as given in [1][8]. In this way we keep in line with the idea of *balances*: from the point of view of our analysis 'feeding' the unemployed workers is not a problem[9]. With this in mind, we shall rewrite the model ([1], [2]) as:

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[7] Below we shall define a sector as consisting of a set of identical firms. Thus, if δ percent of the firms is lost, also δ percent of the sector's capacity is lost. This definition in later work, of course, should be replaced by a more appropriate one that recognises the aggregation issues involved in defining a 'sector'.

[8] However, we shall assume that proportions within the final demand basket remain the same.

[9] Evidently, in reality the economy still has to pay the unemployment benefits. That, however, is a matter of post-flood assistance, and shall be dealt with later.

$$x^0 = A^0 x^0 + \left[\left(\frac{f^0}{L^0}\right) l^0\right] x^0 \qquad [3]$$

Now let us go to the inter-industry transactions matrix M^0. We define it as:

$$M^0 \equiv \left[A^0 + \left(\frac{f^0}{L^0}\right) l^0\right] \hat{X}^0 \qquad [4]$$

where $\hat{X}^0$ is a diagonal matrix with sectoral outputs x_i^0 at its main diagonal. The term in brackets on the right-hand side thus consists of two matrices, both of which have fixed coefficients. Post-multiplication by $\hat{X}^0$ gives us in *nominal values* both the inter-industry use of goods, and the purchases of final demand by the workers, separately recorded for each sector. The submatrix $[(f^0 / L^0)\, l^0\,]\hat{X}^0$ stands for workers' real wage, modeled as a package of goods consumed, of dimension $[n \times n]$. Provided all workers have the same preferences, vertical proportions are the same for all sectors, whereas between the sectors proportions differ according to the number of employees.

Below we shall develop our argument starting from a supposed detailed knowledge of the geography of disrupted production as provided, e.g., by today's GIS databases. We shall start from a representation in absolute numbers. This form has certain advantages above other ones. For example, it tells us directly which links exist between intermediate deliveries and final demand. Now let us suppose that a big flood occurs. The extent of the shock can be simulated based on the GIS databases that contain information on the physical location of (the firms making up) the sector (see for example (Bočkarjova, Steenge et al. 2005)b). In the original situation, the columns of matrix M^0 above represent all interactions in the economy. As a next step, we incorporate our knowledge about the extent of the damage. If sector *i* has lost $100\gamma_i$ percent of its capacity, we shall interpret this in the sense that, immediately after the shock, this particular sector is able to produce $100(1-\gamma_i)$ percent of its potential output if the inputs required to maintain this production level are available, and can be used in the traditional way[10].

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[10] That is, as prescribed by the i^{th} column of the coefficients matrix A^0 in [1].

We shall start from matrix M^0 as defined above (see formula [4]). We recall that the elements of *M* are the sum of the flows of intermediate deliveries and the imputed parts of final demand. We have, for each individual element of M^0 *just before* the shock:

$$M_{ij}^0 = Z_{ij}^0 + F_{ij}^0 , \qquad [5]$$

where $Z_{ij}^0 = A_{ij}^0 x_j^0$ - nominal inter-industry transaction matrix, and where F_{ij}^0 is the i^{th} element of $\left(\frac{f^0}{L^0}\right) l_j^0 x_j^0$.

So, using [5], we have:

$$M^0 = \begin{bmatrix} M_{11}^0 & \cdots & M_{1n}^0 \\ \vdots & \ddots & \vdots \\ M_{n1}^0 & \cdots & M_{nn}^0 \end{bmatrix} = \begin{bmatrix} Z_{11}^0 + F_{11}^0 & \cdots & Z_{1n}^0 + F_{1n}^0 \\ \vdots & \ddots & \vdots \\ Z_{n1}^0 + F_{n1}^0 & \cdots & Z_{nn}^0 + F_{nn}^0 \end{bmatrix} \qquad [6]$$

We now use our assumption that the elements of M^0 stand for units that can be identified from the knowledge of the GIS data system, and that we possess exact information of the amount of productive capacity that is lost. At this stage a modeller runs into a problem of having to decide to which extent (if any) intermediate and final consumption are affected. In principle, this can be deducted from the chain reaction within an economy. In the flooded area production facilities become dysfunctional, thus there is (temporary) no work for workers, thus also no income. With the decreased income, the consumption is also hampered. For expository reasons we shall for the moment assume that both categories of demand are affected in the same way percentage-wise[11].

So, with the fraction of productive capacity that is *lost* in sector *i* denoted by γ_i ($0 \le \gamma_i \le 1$), we now can write:

$$M^0 = \begin{bmatrix} \gamma_1(Z_{11}^0 + F_{11}^0) + (1-\gamma_1)(Z_{11}^0 + F_{11}^0) & \cdots & \gamma_n(Z_{1n}^0 + F_{1n}^0) + (1-\gamma_n)(Z_{1n}^0 + F_{1n}^0) \\ \vdots & \ddots & \vdots \\ \gamma_1(Z_{n1}^0 + F_{n1}^0) + (1-\gamma_1)(Z_{n1}^0 + F_{n1}^0) & \cdots & \gamma_n(Z_{nn}^0 + F_{nn}^0) + (1-\gamma_n)(Z_{nn}^0 + F_{nn}^0) \end{bmatrix} \qquad [7]$$

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[11] For the general case, this can be modified straightforwardly.

We can re-write this equation, splitting it into two parts. Thus we can single out the elements that are not there anymore from the I-O entries that represent firms that remain active. We have:

$$M^0 = \begin{bmatrix} \gamma_1(Z_{11}^0 + F_{11}^0) & \cdots & \gamma_n(Z_{1n}^0 + F_{1n}^0) \\ \vdots & \ddots & \vdots \\ \gamma_1(Z_{n1}^0 + F_{n1}^0) & \cdots & \gamma_n(Z_{nn}^0 + F_{nn}^0) \end{bmatrix} + \begin{bmatrix} (1-\gamma_1)(Z_{11}^0 + F_{11}^0) & \cdots & (1-\gamma_n)(Z_{1n}^0 + F_{1n}^0) \\ \vdots & \ddots & \vdots \\ (1-\gamma_1)(Z_{n1}^0 + F_{n1}^0) & \cdots & (1-\gamma_n)(Z_{nn}^0 + F_{nn}^0) \end{bmatrix} \quad [8]$$

We now turn to the second term on the right, which gives us the information we possess on the parts that have *not* been lost. If we denote the total of the i^{th} row of the second matrix on the right-hand side by the symbol x_i, we have, in input-output 'fashion', the following.

$$\begin{bmatrix} (1-\gamma_1)Z_{11}^0 + & \cdots & + (1-\gamma_n)Z_{1n}^0 \\ \vdots & & \vdots \\ \vdots & \ddots & \vdots \\ (1-\gamma_1)Z_{n1}^0 + & \cdots & + (1-\gamma_n)Z_{nn}^0 \end{bmatrix} + \begin{bmatrix} \sum_i (1-\gamma_i)F_{1i}^0 \\ \vdots \\ \sum_i (1-\gamma_i)F_{ni}^0 \end{bmatrix} = \begin{bmatrix} x_1 \\ \vdots \\ \vdots \\ x_n \end{bmatrix} \quad [9]$$

The above equation system evidently 'looks like' an I-O system. But is it? For example, the balances now neatly add-up horizontally, but does looking at the individual column of the matrix to the left make sense in terms of a production process?

First of all, we should keep in mind that equality [9] is the best survey of still existing productive capacity that we possess about the economy in its totality. It can be viewed as a first effort at "bookkeeping" of the disaster aftermath. Let us call this the *Basic Equation*. However, this equation is indeed only a "bookkeeping" identity.

Second, if we look closer at the equality, one may notice that in principle the relations within the columns of the intermediate part are the same as initially. This is due to the fact that each column is respectively multiplied by the same percentage of the remaining activity, ($1-\gamma_i$). This, actually, does not hold true anymore if we do calculate the standard production coefficients, as the column and row totals are now changed. The nominal relation between the entries in the rows has also changed, as every entry is multiplied by different percentages. We can also see that the structure of the final demand is altered.

As a result, we observe equality [9], describing an economic network that is disrupted in every respect – no previous relationship of production, sales or consumption patterns holds anymore. It cannot be interpreted as an operative I-O system immediately after the flood. In fact, only looking at [9] may severely overestimate real world productive possibilities. We should realise that in order to obtain the final loss figures, we need to run the second step of the procedure here – modelling of the recovery. In fact, in [9] a smaller I-O system is embedded and that should be 'extracted' from it to obtain a realistic picture about the new situation. Below we shall introduce the basic issues for "digging up" the embedded viable I-O system.

5. Recovery Modelling: The Question Of Policy Planning

We assume that in the immediate aftermath of a major disaster it is not clear to each particular agent in the economy what is exactly lost, and which economic connections are still in place. This, in a sense is a state of chaos, which is here systematically described by the Basic Equation [9]. The latter thus only provides the general view from the "bird's view", but does not inherit any economic sense. In this situation crucial is the matter of 'correct' (re)distribution of restricted economic resources and the start of recovery. Because the action is needed instantly and the markets on their own are not always able to provide it especially in a relatively highly regulated economy such as the Dutch one, it is important that the government steps in and takes the initiative of steering the processes. At the same time, one assumes that at the moment a catastrophe outbreaks, the government has an idea about the further possible development scenarios and the consequences of those, so it is able to make decisions in the short period of time about which path to follow. A number of choices are to be made, and it is essential that the appropriate incentives be given to the economy. Some of the existing options will be disucced in this section.

One of the biggest dilemmas, mathematically speaking, if we want to bring the equality [9] to the economically feasible equilibrium is the choice of an anchor. This means that we have to decide what is our starting point: the intermediate demand (basically all inputs into the industrial core of the country), the final demand (such as households, investment demand, government demands, exports), or the total output. On the economic side, this stands for what we may wish to restore as much as possible. If we choose for the production network, we are thus prioritising the intermediate demand for inputs. On the other hand, we may consider important to satisfy the urgent consumption needs that appear in the disaster aftermath, thus infusing means into the final demand. Finally, it can also be decided that the economy having lost a part, should utilise its every cent, thus adjust to the circumstances (for example, adapt new production processes, substituting the missing inputs with the available ones) and use every possibility to maximise the total output. We shall try to go through these broad options in this section. Let us have a look at various options of recovery policy steering and the respective economic response patterns to these.

5.1. Government policy in a rigid economy

We start from the "bookkeeping" system as described by the equality [9]. First consider the vector of total final output, *X*. As pointed out in the previous Section, it 'has the look' of a total output vector[12]. However, it is an important question to ask, which coefficients matrix should be associated with it. Here again we have several possibilities. Let us see what the old coefficients matrix A^0 in [1] tells us, and let us ask if final demand as given by the Basic Equation [9] is compatible with an economy that produces a total output vector $X=[x_i]$ employing technology A. Under the unchanged pre-disaster technology A^0 we have from [9]:

$$\begin{bmatrix} (1-\gamma_1)a_{11}^0 x_1^0 + & \cdots & +(1-\gamma_n)a_{1n}^0 x_n^0 \\ \vdots & \ddots & \vdots \\ (1-\gamma_1)a_{n1}^0 x_1^0 + & \cdots & +(1-\gamma_n)a_{nn}^0 x_n^0 \end{bmatrix} + \begin{bmatrix} \sum_i (1-\gamma_i)F_{1i}^0 \\ \vdots \\ \sum_i (1-\gamma_i)F_{ni}^0 \end{bmatrix} = \begin{bmatrix} x_1 \\ \vdots \\ \vdots \\ x_n \end{bmatrix} \qquad [10]$$

So that finally we obtain:

$$\begin{bmatrix} a_{11}^0 & \dots & a_{1n}^0 \\ \vdots & \ddots & \vdots \\ a_{n1}^0 & \cdots & a_{nn}^0 \end{bmatrix} \begin{bmatrix} (1-\gamma_1)x_1^0 \\ \vdots \\ (1-\gamma_n)x_n^0 \end{bmatrix} + \begin{bmatrix} \sum_i (1-\gamma_i)F_{1i}^0 \\ \vdots \\ \sum_i (1-\gamma_i)F_{ni}^0 \end{bmatrix} = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} \qquad [11]$$

Here a number of issues come up to the surface. Similarly to the question about the new distribution of the displaced final output between the intermediary and final demand, here we are interested to know, if the new vector of total output, *X*, is compatible with the final demand in the

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[12] Recall in I-O analysis total output is obtained by solving equations like [3.1] above. Here the 'total output vector' has simply been obtained by addition of the terms on the left-hand side of the basic equation [3.9].

equation [13]. Also, does this new level of f, 'maximal' final demand, fit the sales pattern of final demand? We shall compare this final vector in [13] with the composition of pre-disaster f^0 reflecting the preferences in the pre-disaster (equilibrium) situation. Next, we would like to see the change in total output level with respect to the pre-disaster level. Thus, what is the relation between X^0 and X?

Assume, government policy priority is to stimulate the final consumption. Let's also assume that after the outbreak of a disaster the actual economic system is rigid, and its structure stays the same, i.e. technical coefficients do not change. As far as we know the maximum output level x and the a_{ij}'s from [11], this time we will rearrange the basic input-output equation [1], making the final demand an unknown. We will assemble the residient capacity coefficients $(1–\gamma_i)$ with the respective elements of x^0. To ease the matrix notation, let's introduce $(I – \Gamma)$ for the diagonal matrix with $(1 – \gamma_i)$ at the i^{th} location on the main diagonal:

$$(I-\Gamma)=\begin{bmatrix} 1-\gamma_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1-\gamma_n \end{bmatrix} \qquad [12]$$

Then we should get the following equality:

$$(I – \Gamma)\, x^0 = A^0\, [(I – \Gamma)\, x^0] + f^1 \qquad [13]$$

Now let us express the final demand as a variable of interest through the known ones:

$$f^1 = (I – \Gamma)\, x^0 - A^0\, [(I – \Gamma)\, x^0] \qquad [14]$$

Now again we face several decisions. First of all, we have to compare f^1 with final demand in [13], in the 'just after disaster' situation, and take a look at the difference. Secondly, suppose this f^1 is feasible. We have to ask if it is economically acceptable and if it is in line with the traditional preference pattern.

Besides, we may assume that the initial structure of final demand (before the disaster) does not change, as consumers' preferences stay mainly the same, even after a calamity shock. Therefore, we provide the system [14] with a restriction over the structure of final demand. Thus, in mathematical terms this means that we have to model output on the basis of the following formula, replacing final demand in the standard formulation by $[\varepsilon f^0]$,

$$x^2 = A^0 x^2 + \varepsilon f^0, \qquad [15]$$

where ε is the is a scalar, so that $0 \le \varepsilon \le 1$.

Finally, suppose that in the post-disaster situation government policy is aiming at pursuing final demand maximisation. Let us see what kind of effects will be rippled throughout the economy then. In our notification this will end up in the maximisation problem such as

$$\begin{cases} \boldsymbol{max}: \rightarrow & x^2 = A^0 x^2 + \varepsilon f^0, \\ \text{s.t.} & x^2_i \le x^0_i (1 - \gamma_i) \end{cases} \qquad [16]$$

In effect if we rearrange the objective function, mathematically it will suggest that the output levels should also decrease by the same proportion as the final demand, i.e.

$$x^2 = \varepsilon x^0, \qquad [17]$$

and we obtain

$$\varepsilon x^0 = (I - A^0)^{-1} \varepsilon f^0 \qquad [18]$$

it therefore can be concluded that

$$\varepsilon = max \{(1 - \gamma_i)\}. \qquad [19]$$

Equation [19] shows the optimum in the after-shock situation, provided the rigidity of the sectoral production functions and final demand structure. In this case the government policy of supporting the final consumption would lead to the market response of shrinking in both output and final demand by the proportion of the most disrupted sector. This sector will evidently act as 'bottleneck' for the whole economy. Consequently, final demand (especially for the less damaged sectors) will also be far under the highest possible level as seen in [9].

This means that domestic production, being hampered by the rigid production functions, cannot keep up with the desired level of the final demand. However to satisfy this gap, imports can be sought. This would lead to the deterioration of current account and possibly increase in government debt on the one hand, as well as long-run imports substitution for domestically produced goods on the other hand. If home production gets crowded out in the medium and long term, this would lead to the drop in economic interactions and consequently to the decrease of economy multiplier (as part of previously domestic activity is leaking out). The result of that would be the lower development path of the whole economic system, which is becoming reliable on imports, and thus more vulnerable to outside shocks.

Note, that in case the shock to the system is homogeneous ($\gamma_i = \gamma$, all sectors are hit to the same extent) instead of equation [13] we have

$$(1-\gamma)A^0x^0 + (1-\gamma)f^0 = (1-\gamma)\,x^0, \qquad [20]$$

which is nothing but equation [1], multiplied by the factor $(1-\gamma)$, with total output being $X=(1-\gamma)x^0$. So, this particular input-output equation shows that output just declines at the same rate for each sector, and no indirect effects are observed. This is consistent with the conclusions we find *inter alia* in (Cochrane 1997)a, p.2.

5.2. Government policy in a flexible economy

On the other hand, suppose that producers are able to adjust to the new circumstances via shifts in production technology. Let us see how in case of extreme flexibility the new technology matrix will look like. We start again from the *Basic Equation* [9], and we will try to determine a new coefficients matrix, starting from our knowledge of maximum possible output after a disaster x. We now identify 'flexibility' as a situation when an economy is capable of extreme technology adaptability to employ its resources at most at the moment of restricted output. Thus, we fix x. We then have:

$$\begin{bmatrix} (1-\gamma_1)Z_{11}^0 + & \cdots & +(1-\gamma_n)Z_{1n}^0 \\ \vdots & \ddots & \vdots \\ (1-\gamma_1)Z_{n1}^0 + & \cdots & +(1-\gamma_n)Z_{nn}^0 \end{bmatrix} = \begin{bmatrix} \tilde{a}_{11}\,x_1 & \cdots & \tilde{a}_{1n}\,x_n \\ \vdots & \ddots & \vdots \\ \tilde{a}_{n1}\,x_1 & \cdots & \tilde{a}_{nn}\,x_n \end{bmatrix} \qquad [21]$$

As far as we have fixed for the time being the output level at its new post-disaster maximum level, the only unknown now is the technology, i.e. $\tilde{a}_{ij}$ coefficients. This procedure results in a new coefficients matrix, to be called $\tilde{A}$. The link between $\tilde{A}$ and A^0 can be established via a so-called new E-function, such as:

$$\tilde{A} = E(A^0) \qquad [22]$$

Finally, steps one and two of the procedure described above are the possible operationalisation of the Event Matrix, as it reflects any changes in the initial IO matrix. This means that the Event Matrix is merely anything that makes A^0 transform into $\tilde{A}$.

If we confirm along this path, we shall face the task to define a proper set of properties for the form of E matrix to satisfy the transformation and matrix $\tilde{A}$ to be acceptable as I-O based technology matrix. However, a full exploration will have to be the subject for later and more detailed work.

It is important to observe here, that the approach we have presented is not an exhaustive coverage of the issue of disaster modelling within the I-O framework. It should rather be seen as the way of thinking about how things might work, applying it to the rich though not yet fully uncovered features of the I-O model.

This type of analysis can be extended and applied in bi- or multi-regional frameworks. By doing so one will be able to capture additional economic insights of the performed analysis. There are more possibilities that can be offered by the model. Providing the methodologically sound ground for the large-scale calamities, we suggest that it is a suitable model for empirical studies. The theoretical and empirical applications are well compiled in the model. Besides, featuring the synthesis of theory and practice the model as we suggest it is a good candidate to be used for policy analysis and eventually advice. Ultimately, the Basic Equation can be an alternative starting point for use for other models, for example as input for CGE recovery modelling. However, the latter is left as a proposal for the further work in the disaster analysis field.

6. Conclusions

In this paper we have proposed a theoretical foundation based on I-O methodology for problem approach of severe changes in economic structure. The notion of economic network disruption and disequilibrium are in the centre of the discussion. We put forward that it is extremely important to have a good basis for discussing the consequences of the catastrophe and the subsequent recovery period. We propose to take a new look at the IO model, refining it in a more flexible manner. We have derived what we view as a '*Basic Equation*' and discuss its applicability. This identity serves as a starting point for investigating various resilience issues and may lead to a better presentation of the concept of an 'Event Matrix'. The use of GIS data offers broad opportunities in aggregation: only availability of IO tables poses the limits.

We have also discussed the choices that exist in the immediate aftermath of a disaster for recovery and reconstruction processes. Being a crucial point for finding the future development path, recovery should be well managed. We suggest that government in the post-calamity stage takes action to steer the recovery. However, it has to have a clear picture of the existing policy options and their respective consequences. We have discussed two policy possibilities in particular, and have concluded that the final demand maximisation target under the conditions of rigid adjustment (i.e., consumption and production patterns stay as in the pre-disaster situation) will lead to the very restricted response of the economy in terms of total output. This may translate into the high loss figures and the impeded long-run recovery. However, if the economy has enough flexibility to adjust to the new circumstances, indirect losses may be minimal and the new (improved) economic structure may be under way.

The approach described in the paper has wide application possibilities as in the theoretical as in the empirical areas. Having provided the improved theoretical grounds for major disaster analysis within the IO framework, it is also well coupled with the data needs on the empirical level. Finally, being an excellent tool for scenario generation, it offers ample opportunity for policy analysis and policy advice.

Possible extensions of the model are in the areas of multi-regional analysis, as well as coupling with other approaches in the disaster economic consequence analysis. These points are put on the future research agenda.

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