CHAPTER 8

STRUCTURAL ECONOMIC EFFECTS OF LARGE-SCALE INUNDATION

A simulation of the Krimpen dike breakage

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Abstract: The paper's main concern is to establish a general methodology for economic loss estimation as a result of a large-scale flooding. The issue of economic loss definition is addressed in an attempt to unify the scattered definitions currently circulating in the 'disaster' literature. Total effect includes the direct loss to households and government, direct business interruption and induced indirect losses on production all over the country. The input-output model is proposed as a basic modelling framework. The discussion involves appropriate definition of direct and indirect costs within this framework. Adaptations to the model are proposed to account for asymmetric shock aspects such as 'production bottlenecks' and substitution effects. The time dimension of the model is a 2-year period. A bi-regional input-output table is utilised for tracing the inter-regional ties within the country and to estimate the disaster-induced changes of the economic structure

The case study of a dike breakage in the province of South Holland in the Netherlands provides an example of modelling vast economic consequences. Two basic models are compared: a reference standard input-output damage evaluation model and adjusted models examining the impact of economic recovery of production 'bottlenecks' and substitution effects from imports and production transfer to other regions. It is shown that with the same level of initial disruption final loss figure depends on the ability of an economy to adjust. Whereas the presence of 'bottlenecks' in the after-flood situation drags the final estimate far below the reference figure, the emergence of flexible conditions for the economic response provides more optimistic results

Keywords: large-scale flooding, direct and indirect economic loss, economic structure

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S. Begum et al. (eds.), Flood Risk Management in Europe, 131–154.

1. INTRODUCTION

Tsunamis, floods, droughts, hurricanes and earthquakes are a constant threat to society. In the past decades we observe a growing awareness of the devastating effects of these natural disasters on the economies of developing and developed countries. The World Bank, the United Nations and the European Union have published a number of reports on this problem, *inter alia* Kreimer and Arnold (2000), Freeman, Martin et al. (2002), ECLAC (1991), ISDR (2002), Colombo and Vetere Arellano (2002). Parallel to this policy awareness we note a strong interest in the methodology of estimating the economic consequences of disasters on welfare and an interest in the effects of recovery plans for the economy.

In this research we are interested in the economic consequences of flooding. Specifically, we are concerned about the effects of large scale flooding in the Netherlands. Sea level rise and an increased probability of flooding of polders along the Dutch rivers ask for a quick and permanent solution. We may note, however, that there are relatively few reports on the consequences for Dutch society of *large scale flooding*. There are several publications on small-scale floodings, but there is hardly any experience with the societal and economic effects of major floods (van der Veen, Groenendijk and Mol, 2001). In the broader international literature it can also be noticed that the vast majority of academic work dealing with floods focuses on relatively small-scale disasters. This means that the authors are basically concentrating on the micro-level effects of the events, producing cost – benefit analyses for the regional level. Large–scale floodings are thus remain an uncovered issue.

However, American authors open a wider perspective on disaster analysis. They raise the issue of large-scale earthquakes, which are more characteristic for the US. Often American authors discuss the matter of natural disasters in a county-to-state scale. These are not countrywide disasters, as the country itself is big. Nevertheless the mode of analysis is very close to large-scale disaster analysis in a small country. This seems to suggest that core aspects of the methodology used in the earthquake literature can be projected for the case of a big flooding in the Netherlands.

In this paper we will report on first efforts at an empirical analysis of the structural economic consequences for the Netherlands of a dike breakage near Krimpen. The consequence of this dike breakage is a massive flooding of major parts of the Randstad.

In order to be able to deal with the economic consequences of this major flood we first need to establish an accepted definition of damage, which can be used in an economic model of the Netherlands. In Section 2 general concepts of damage are discussed and a consistent system of definitions is presented. In Section 3 the methodology we adopt to simulate a major shock to the economy is introduced, whereas in Section 4 we present the case of the Krimpen dike breakage. The data and the adaptations of a basic model for the affected area (the Province of South Holland) are set forth. We will put forward the input-output model as a basic tool. However, as we shall argue, the standard formulation needs adaptations to give it additional flexibility to model alterations in the production system. We will also present of the results of the case-study calculations. In Section 5 we formulate our conclusions and recommendations for future research.

2. DAMAGE

Van der Veen, Groenedijk and Mol (2001) surveyed the Dutch literature on the methodology of estimating damage. It was concluded that there is no generally agreed methodology, let alone a settled definition of damage. This conclusion is due to the fact that 1) There is no agreement on the economic points of departure; financial appraisals are mixed up with cost-benefit analyses (CBA). In the latter the usual concept is economic costs, which relates to opportunity costs in welfare economics. CBA is a helpful means to weigh alternative measures against flooding, whereas a financial appraisal is often a base for investigating the sum of money to be recovered from insurance companies; 2) There is confusion on the time and spatial scales: financial appraisal limits itself to a single organisation, whereas CBA requires well-defined borders, like a nation, or the European Union; 3) Stock concepts are confused with flow concepts; 4) The borderline between direct and indirect costs is not well defined.

In the following we will concentrate on the latter two points, i.e., stocks versus flows and the demarcation between direct and indirect costs. We will do so by reviewing the international literature. Our point of departure is a national Cost-Benefit Analysis.

2.1. Basic Concepts for Damage Estimation

Twenty years ago Ellson, Milliman and Roberts (1984, p. 559) concluded on the basis of their literature survey that “most of the economic impact literature fails to make proper distinctions between the measurement of loss and the measurement of long run patterns of personal income, employment, and population growth. Much of the research has confused stock and flow concepts in the estimation of loss. Double counting is often involved, and the losses are not estimated in present value term”. Moreover, in MAFF (2000) it is stated that:

> “When identifying and valuing the different streams of benefits and costs, it is helpful to think in terms of *stocks* and *flows*. It is very easy to make the mistake of including the same benefit or cost twice because of a failure to distinguish sufficiently between the stock of some asset and the flow of resources, or consumption, which that stock generates. Typically, stocks give rise to some flow of consumption or resource so that the current capital value of the stock is determined by the discounted value of the future benefits, which flow from it. In some cases the flow diminishes the value of the stock value (e.g. mining coal necessarily diminishes the stock of coal) whereas in other cases it does not (e.g. catching fish at below the rate of replacement). An appraisal can include either the stock value of a resource or the sum of all the flows that it yields but not both.”

The issue of double counting is important in assessing the value of properties. Before we start elaborating on this issue we need to find a definition of both concepts that allows us to make an appropriate distinction between both concepts. We follow Parker, Green and Thompson (1987, p. 36): "*Stocks* are the capital equipment, consumer durables and other physical objects damaged or destroyed by flooding. The *flows* are the flows of national income, which would have been produced by the damaged stocks but are lost after a flood".

The main thrust of the discussion in the literature is to assess the value of the loss. One can measure this value by either taking the stock value or the flow value. It is argued that these values, in theory, represent the same loss. So, when analysing damage that results from floodings, an assessment can be made of both the stock and the flow value of properties. Of course, this is especially relevant in the manufacturing sector.

As a result, in Parker, Green and Thompson (1987, p. 35–37) there is a demarcation between direct costs and primary and secondary indirect costs along this differentiation: *Direct costs* relate to loss of land, capital and machinery, thus to stocks, and primary *indirect costs* to business interruption, a flow. Moreover, secondary indirect effects relate to multipliers in the economy. The authors warn us that it is not allowed to add the first two categories (i.e. direct and primary indirect costs) unless production is lost to foreign countries.

Rose (2002) argues along similar lines. The stock of capital and machinery gives rise to a flow of production and income in the future, which means that business interruptions and capital stock affected measure the same thing. He consequently defines business interruption as a direct cost instead of an indirect one. Rose (2002, p. 2) states that, for several reasons, an estimate based on flows may result in a better estimate than estimating damage based on stocks, or property damage. His reasons are the following: 1) An estimate based on flows makes up a better proxy of the lost value since it also accounts for damage due to business disruptions; 2) Flow measures are more compatible with macro-economic parameters; with respect to this Rose states that a stock based concept may result in an over-exaggeration of damage since only a portion of the property value may translate into service flows in any time; 3) Estimates based on a flow concept are more compatible and more consistent with the distinction between direct and indirect damage; 4) Flow measures have an explicit time dimension, which makes modelling better to do. Cochrane (1997b) extends the definition of direct costs by not only including the physical damage to land, plants and houses, but also induced physical effects, which are the consequence of the disaster.

Finally, in the flooding literature there is a long lasting tradition to include also non-monetary impacts on households (MAFF 2000). To households, impacts of flooding such as increased stress, health damage and loss of memorabilia can be far more important than the direct material damage to homes and their content. Also, there are approaches to include recreational and environmental benefits in flood and coastal defence schemes. In a CBA these benefits show up as avoided losses.

We may conclude that for direct costs there are differences of opinion: Cochrane offers a broad definition by also including induced physical damage. Parker, Green and Thompson differentiate between direct and primary indirect costs along the distinction between stocks and flows, and then warn for not summing up direct and primary indirect costs. Rose states that direct costs can be measured either by stocks or by flows. We will come back to this in the next section.

2.2. Indirect Effects in an Economy

Whereas Parker, Green and Thompson (1987) defined indirect costs as business interruptions and multiplier effects in the economy, Cochrane (1997b, p. 225) defines indirect economic effects more precise as "*a result of dislocations suffered by economic sectors not sustaining direct damage. Activities that are either forward-linked (rely on regional markets for their output) or backward-linked (rely on regional sources of supply) could experience interruptions in their operations*". He thus refrains from business interruptions.

In our view (see also van der Veen et al., 2003), combining the concepts of Cochrane and Rose will solve the existing problem of defining direct and indirect costs: Using a flow-based measurement of economic cost enables the analyst to make a clear distinction between direct and indirect damage. If damage is valued according to a stock-based concept, one is forced to identify property damage as direct damage and to identify damage due to business disruptions as indirect damage. This is not unambiguous since it may introduce double-counting in the analysis. Expressing damage as a flow-based concept gives us an unobtrusive proxy; it enables us to better model indirect damage.

Indirect economic effects are due to relations within an economy. If part of the factories of type B is damaged by a disaster the production of sectors A and C is affected, but also the production of final products (consumption, investment, export and consumption of government) may be hit. From Figure 1 it can be seen that *other* factories of type B in non-flooded areas may take over the production of the damaged factory B.

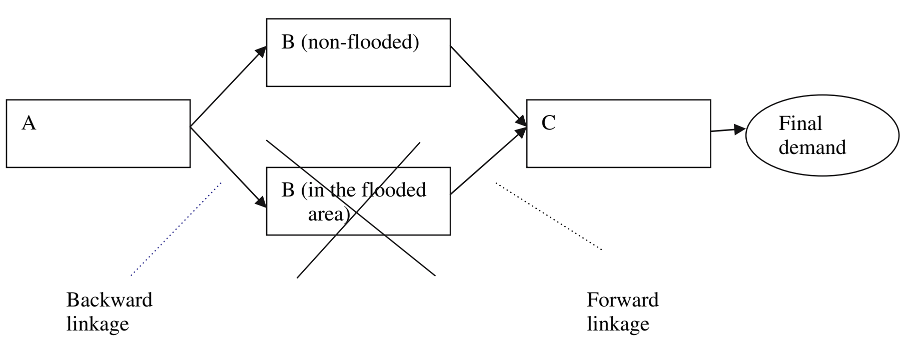

Figure 1. Forward and Backward linkages in an economy, when factory of type B is damaged in a flooded area

The magnitude of these indirect effects depends on: 1) the availability of alternative sources of supply and demand, 2) the duration of the disruption and 3) the possibility to extend production. In general it is very difficult to assess whether alternative sources are available and whether production elsewhere can be relied upon. Detailed market information should be inserted in the model.

2.3. Damage: Towards a Consistent Set of Definitions for Direct and Indirect Costs

To avoid the ambiguities found in the literature[2] we make the following decisions for the classification of damage:

Firstly, for firms we follow a flow concept to estimate business interruption. For households and governments we apply a stock concept. This means that in our view direct costs relate to 1) physical damage to capital assets, including buildings, infrastructure, industrial plants, and inventories of finished, intermediate and raw materials destroyed or damaged by the actual impact of a disaster. Consequently, 1a) property owned by households and government is measured as changes in stocks, and, 1b) business interruption is estimated as a flow for the duration of the flood. In addition there are 2) non-monetary impacts on households. *Secondly*, in order to estimate indirect economic effects we apply the concept of Cochrane of forward and backward linkages. *Finally*, in order to assess total damage an estimate is required for the excess capacity in production in the non-flooded areas and for changes in economic behaviour of firms and households.

In this paper we will focus on the indirect cost concept in damage estimation and apply it to the case study of simulated flood in the Netherlands. Before doing so, we would like to introduce briefly the input-output analysis as a working vehicle for our estimations.

2.4. Input-Output Analysis

We will highlight here the economic model we use. As suggested by the established literature,[3] Input-Output modelling makes it possible to look at the inside of the complex inter-industry linkages within an economic system. Input-Output analysis can be described as an economic method that focuses on the trade pattern between the constituent parts of the economy. These parts can be defined in very general terms, such as producers, consumers, the labour force, governmental agencies and foreign countries. Classifications may vary depending on the level of aggregation. For example, on the production side one may wish to distinguish various types of

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[2] *Inter alia* the World Bank, the UN, IIASA and Swiss Re. See also for reference ECLAC (1991 and 2003), Benson and Clay (2000 and 2004), Freeman *et al* (2002).

[3] S. Cole *et al* (1992), M. Shinozuka *et al* (1998, pp.95–123), B.G. Jones *et al* 1997, pp.223–248), Y. Okuyama *et al* (2002).

industries or sectors such as typical agricultural or industrial sectors, several types of services, *et cetera*. The economic structure itself is modelled in terms of an Input-Output or inter-industry transactions table, which represents the sales from one sector to another. The sales can be between industries, but also between firms and households or between workers and firms.

Row-wise one can observe the intermediate sales and final demand requirements. Former are the sales of goods that are used in the production process. Latter are the sales to households, business investments in fixed capital, government investments and exports. Alternatively, column-wise one can trace 'production functions'. This means that vertically a table reflects all expenditures for intermediary purchases (form various sectors) and other expenses, such as labour, taxes and imports.

The pattern of deliveries is interpreted in terms of regularities in the table, which can be analysed using various mathematical techniques. In conventional notation x is referred to as a vector of total sectoral outputs, f – as a vector of final demand, (Ax) – nominal table of intermediary inter-industry sales and purchases, and A is the symmetric matrix of (constant) input coefficients. Total output of each sector is used for intermediary production and final consumption by households (including exports), which can be reflected as follows:

$$(2.4.1) \quad x = Ax + f$$

The conventional relationship between the total output and final demand is established by

$$(2.4.2) \quad x = (I - A)^{-1} f$$

where $(I - A)^{-1}$ is the economy multiplier matrix also known as the Leontief inverse (see Miller and Blair, 1985, pp. 100–147). Knowledge of matrix A enables us to calculate the effects of shifts in demand via the so-called multiplier analysis. The basic problem in analysing the economic consequences of disasters like flooding or earthquakes is that it requires modelling of *disruptions* in the existing trade patterns. Essentially, we shall try to bring additional consistency to existing modelling.

3. CONSEQUENCES OF A SHOCK TO AN ECONOMY: BUSINESS DISRUPTION

The literature on disaster analysis provides us with several approaches for the problem of estimating the economic costs of a devastating event. However, as we just mentioned, there is still no single unified method available to deal with the consequences of a large-scale disaster, nor there exists an agreement on the exact definitions of major loss concepts. Given the large choice of model variations, we shall first outline the crucial features in disaster model building, looking at a post-flooding situation through an economist's eyes.

3.1. Asymmetric Shock

As the water starts to inundate the region, we will see a large number of production sites affected. In the case of a large-scale catastrophe production in the flooded area might be completely lost for at least a year and might hardly recover during the next year (especially in the Netherlands where water might stay in a polder for a relatively long time – due to the specific geographic features of the country). Therefore, we do not need special theoretical assumptions for the evaluation of direct output damage in the affected area: 100% of production will be lost. We also have to take account of the fact that the flooded factories in general may belong to different branches of industry and that they may be of different size and production capacity. Therefore, aggregating the losses of each production facility and bringing it to the industry level results in what is known as the paradigm of asymmetric shock. That is, different industries within the province (and hence the country) suffer a different level of output failure.

There exist various methods for asymmetric shock implementation. A promising option is offered by Cole et al. (1993, p. 3–13), where a device to formalise the interference into the input-output matrices is presented. He introduces the so-called Event Accounting Matrix (EAM) to trace all the changes induced on the transactions matrix A (see section 2.4). This Event Matrix is meant to absorb the reflections of the changed situation in the production sector in time. Yet the theory behind the EAM is evolving.

As a first step, modelling requires imposing an initial impulse on the whole system. Rose (1998) suggests that employment loss coefficients can in principle be used to model the change in output assuming that sectoral output is evenly distributed among employees. Therefore, the chain of causality in our case is as follows. Production changes are assumed to induce final demand changes. That is, we relate the loss estimation data to the final demand dimension of the transactions matrix. We model our *initial impulse* as follows:

$$(3.1.1) \quad \Delta f_j = \varepsilon_j \cdot (f_j)_0,$$

where Δf_j is the final demand change for each sector j; $(f_j)_0$ is the pre-disaster final demand level for sector j; ε_j is a fraction of sectoral production lost ($0 \leq \varepsilon_j \leq 1$).

3.2. Production 'Bottlenecks'

A 'production bottleneck' in an economy can be broadly defined as a situation in which overall production is jeopardised by one of the sectors, for whichever reason, so that it is unable to supply the necessary inputs to other sectors. Several causal factors are at work here. The structural factor is the existence of so-called 'key industries' in an economy. When, as a result of a natural disaster an uneven loss of production throughout the sectors in the region is observed, these sectors become especially crucial. For example, if a small industry is heavily damaged (being a highly important source of input for other industries), it will trigger over-proportional losses in other industries, for which it acts as a supplier.

Other causes of the emergence of production 'bottlenecks' (let's call them institutional factors) are imports possibility limitations, payment lags, contract rigidity, etc. As the literature suggests (Cochrane 1997a, p. 3; Benavides et al. 1998), the existence of such bottlenecks can substantially raise economic loss expectations.

In the input-output tables a 'bottleneck' is reflected as sharply reduced transactions between the industries, which depend most on such key sectors.[4] Unless an economy can resist the initial shock and adjust, ε_j (see formulae [3.1.1.]) for each sector becomes $max(\varepsilon_j)$, i.e. down to the level of the most suffering industry.

3.3. Lifeline System

A significant source of additional production disruption in the literature concerns so-called 'lifelines'. These include infrastructure facilities (roads, railroads, air transport), utilities (electricity, gas, water supply, sewage system) and communication services. Many authors have emphasized their prominent role in contributing to losses.[5] Many economic transactions depend directly on physical lifeline systems – for example, purchases of power and water by businesses and households, the trucking of goods between the industrial areas and to markets, the flow of information within and beyond the region. Even in cases when a disaster has a limited direct impact on a region under effect, the indirect medium-term impacts might be much more devastating across the local economy, including areas outside the affected region.

Important is the observation that (even) a partial disruption of lifelines brings about larger negative effects than can be viewed directly from an input-output table. As indicated by Tierney and Nigg (1995), "data on the business impacts of the 1993 floods indicate that lifeline service interruptions were widespread, were perceived by business owners as very disruptive, and were a much more significant source of business closure than actual physical flooding".

Based on the approach suggested by Chang (1997, p.82) and Rose et al. (1997, p.96) 'lifeline disruption effect' functions can be estimated for each branch of industry. Alternatively, Okuyama et al. (2003, p.11) offers to model lifeline collapses via the imposition of final demand drop impulse due to the interruption in lifeline services on the post-disaster input-output table with adjusted coefficients.

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[4] There has been no unanimity over the unified definition of a 'key sector' in the literature (see for example Hazari 1970, Beyers 1975). Nevertheless, the main characteristic usually considered in this kind of analysis is backwards and forwards effects. When a sector has relatively high effects in both ways, there are grounds to conclude that it is an expected candidate for a 'key industry' nomination.

[5] See, e.g. in Cole (1992) and Shinozuka *et al* (1996).

On top of that, one should also consider that lifeline networks make up a complex lifeline system. The CAE Report (1997, p.12) asserts: "But, most importantly, in most cases there is a high level of interdependency between lifeline services. Each lifeline generally needs the others in some way". However, Rose et al. (1997) note that modelling the cases involving several lifeline element disruptions is not a straightforward task. The reason is the presence of non-linearity of these interdependency effects. The CAE Report makes a step further, exploring lifeline interconnectedness. It distinguishes between the interdependence of lifeline networks in operation (if A fails, B fails), and in response (need to fix A to get to B).

We recognise the importance of lifeline networks failure as a result of a vast flood, their interconnectedness and loss 'spillover' effect on the other sectors, thus leading to the vulnerability of the final indirect loss estimates. Yet, particularly in our empirical example, we are not able to evaluate precisely lifeline disruption effects due to the lack of specific input information about its direct losses. We shall keep lifeline degradation study as an important area of our future research. Though, we suggest that for the time being it can be partially accounted for as a short-run bottleneck for the whole region affected by a disaster.

3.4. Substitution Effect

How do producers react on a shock? The key notion here is *substitution*. Each industry has a number of choices for production and/or consumption substitution. First of all, as a result of a major flood a certain amount of production will be lost. However, production substitutes may arrive through imports. This in effect means that domestically produced goods are substituted for the ones produced abroad. Secondly, after the initial shock to the economy the system adjusts and starts to recover. Due to possible excess production capacities in the rest of the country, producers outside the flooded area may overtake part of lost production. Therefore, with substitution an inter-regional shift of production will be observed[6] and recovery will have a broader spatial dimension (see also Figure 1). This will obviously moderate the total loss figures for the entire country as economic activity revives.

3.5. Other Factors

At the same time as the flood expands, the population become affected: people loose their jobs and become unemployed. This causes on the one hand a decrease in welfare, and on the other hand additional government expenditures for the

[6] It should be noticed here that production substitutability highly depends on the excess production capacities of the factories in the areas outside the affected region. This issue also needs additional attention before industry substitution coefficients are obtained.

unemployed. This goes beyond the 'human' face of the story. People lose their homes, need to be evacuated from the flooded area and be settled in other places, which also gives rise to government expenditures, not to mention such intangible effects as the social and psychological impacts. Though these stand beyond the scope of this paper.

Eventually, recovery programmes are launched by governments to soften the consequences of a disaster, namely to help the restoration of the distorted area, the reconstruction of vital lifelines, thus favouring the boost of economic activity. We are not directly estimating the volumes of these investments to include them into the model, though indirectly we take this aspect of recovery into account.

Finally, we have to consider the time aspect of the analysis. First, we witness vast disruptions taking place in the flooded area, spreading also to the rest of the country. Then we observe adjustments of the economy to the new conditions. Not all studies take time dimension into account, although it plays an important role in a coherent economic development when disaster recovery plans are drawn. We will to an extent consider time in our model, as far as we take into account a 2-year time span. We will impose an initial shock on the system, suggesting that the adjustment will start with the second year. We will distinguish between three possible scenarios.

4. THE CASE OF KRIMPEN: CALCULATIONS

4.1. The Data

In our case study we simulate a massive flooding in the Province of South Holland of the Netherlands. This area was nearly inundated in 1953. Flooding was prevented by sailing a boat into the dike breakage.

Delft Hydraulics provided us with the relevant hydrological data with which we are able to compute water depth in a GIS environment. Figure 2 shows the Province of South Holland and the flooded area. In order to compute damage and production loss on the disaggregated level of a GIS it is necessary to combine the geographic characteristics of the inundated area with available aggregated statistics on production and value added for the province of South Holland.

At our disposal we have a data set, which is applied in the Dutch HIS-SSM (Vrisou van Eck and Kok 2001) damage model. The dataset is generated with the D&B Marketeer & Prospector. This data set contains information on location, size (number of employees) and sort of economic activity (expressed in a 4 digit SIC-code) of any place in the Netherlands for the year 2002. The spatial element is a six-digit zip code. Combining the data results in a database in which we have georeferenced data on economic activities (sort of activity and size of activity) per zip code. Schematically, this is represented in Figure 3.

Another set of available structured data is a regional transactions matrix that is used to model the relations in an economy. We use a bi-regional transactions

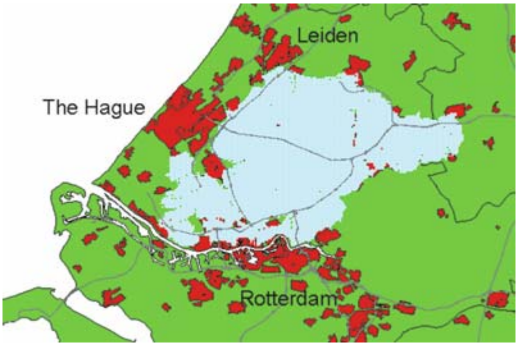

Figure 2. Map of the hydrological model simulation

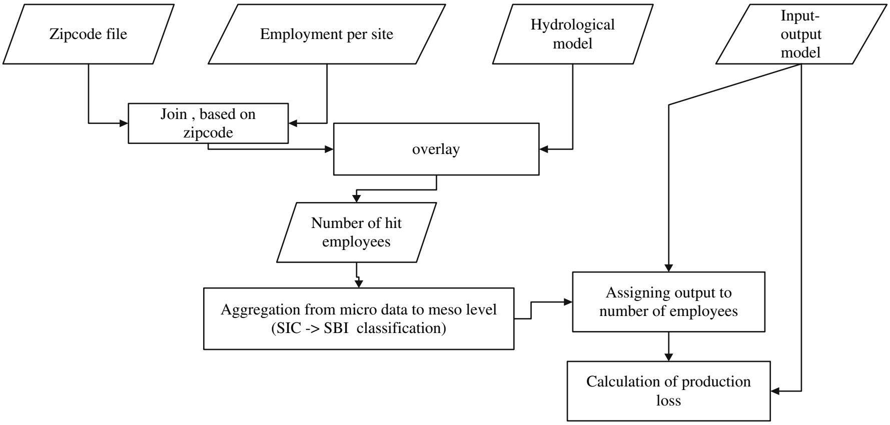

Figure 3. Flowchart of data and data manipulations

matrix in which the economy is represented by the transactions matrix between 39 sectors in South Holland and the rest of the Netherlands. The transactions table was constructed by Groningen University and the Central Bureau of Statistics according to a semi-survey method. The table contains information for the year 1992 on transactions in a SBI format.[7]

[7] With regard to the validity of combinations of the datasets, we should make a reservation. The input-output table itself was set up for the time-period of 1992–1997. This means that the precise data on the transactions may be somewhat outdated. However the literature (Eding, Stelder et al. 1995) suggests the main characteristics of the economic structure essentially remain unchanged. Therefore, the use of the employment data for the year 2002 for flood simulation under such assumption can be justified. At the same time it is acknowledged that this time-inconsistency of data sets might partially undermine the accuracy of the obtained results.

4.2. Direct Damage Estimation

In Section 2 we concluded that a consistent measure of damage to households is the "stock" measure and that the measure for business activities is the "flow" measure. The damage to households is in our case calculated using the HIS-SSM damage assessment program. Damage to firms (direct and indirect) is assessed by our economic model, based on input-output framework. The latter will be presented in detail in Section 6.

Damage to households refers to the value of replacement of the destroyed objects. In HIS-SSM we take the damage to *infrastructure, buildings and urban property* (for estimates see Vrisou van Eck and Kok, 2001).

In turn, in order to estimate the direct damage for business activities the vast disaggregated GIS data base with the appropriate GIS software[8] is coupled with economic and hydrological data to select the zip codes, which are hit by the flood (as also described in Chang, 1997, p.80). This in turn provides us with the number of employees that are affected by the flood.

We obtain the vector of lost employment by sector, ε_j, where each coefficient is calculated by relating the number of employees in a sector that are affected by the flood, by the total number of employees in a sector in the province.

$$(4.2.1) \quad \varepsilon_j^{ZH} = \frac{N_j^{affectedZH}}{N_j^{ZH}}$$

By doing so, we aggregate micro-data to a meso- and a macro- level. The result of this process is a proxy for business disruption that can be used as a starting point to estimate indirect damage.

4.3. Indirect Economic Effects

For our empirical exercise we face a number of problems. One of the major ones: how to introduce business disruption estimates into our transactions matrix (see section 2.4). We do not have information about the intensity of transactions between producers in the flooded area, where activity will terminate, and in the remaining Province of South Holland. This in effect becomes the core issue of the adaptations to be performed during the first stage in our model. There are a number of possibilities in the attempt to overcome this difficulty.

As soon as the direct business interruption damage is assessed and translated into a loss of flow of produced outputs, it is ready to serve as an input for input-output table transformations. There are two possibilities to assess the indirect loss: via the standard model multiplier or with some adaptations of the input-output framework. Exercises along the lines of the latter model are of most interest here; nevertheless

[8] Arcview (*http://www.esri.com/software/arcview/index.html*).

for comparison we will provide the estimation with the standard model. The standard indirect effects in the course of calculations are obtained with the help of the IRIOS programme.[9] Adaptations are handled via adjustments for economic resiliency and for the 'bottlenecks'. We shall thus discriminate between 3 scenarios. For all the cases we look at the loss as a result of 2 years of economic system adaptation to the initial flood shock.

4.3.1. Scenario I –standard exercise

This scenario is presented as a 'point of departure' for the comparison with the other two scenarios. It genuinely presents the procedure using the (rigid) standard assumptions of the conventional input-output model.

Step 1. As far as production is interrupted in the flooded area, it causes a decrease of output in the province. The estimate of direct loss due to production activity interruption is provided for each sector in terms of a fraction of lost employment in the province of South Holland (ε_j^{ZH} as in formulae [4.2.1]). It will be multiplied by the vector of final demand to obtain a change of final demand (as a consequence of output drop). Then, indirect production effects will be obtained with a help of simple multiplier.

$$(4.3.1.1)\ x_0^{St} \rightarrow x_1^{St} : \Delta x_{indirect} = (I - A)^{-1} \Delta f_{direct}$$

As a result, a decrease of the intermediate output level in the South Holland province and in the rest of the country will be observed. Consequently, it will also become reflected in decreased employment throughout the country and in changed imports.

Step 2. Induced effects on the economy are caused by lifeline collapses, which imply extra output losses to the remaining production. An additional decline in activity happens 'on top' of the initial shock during the first year after the start of the flood and is introduced in the model via final demand decrease.

$$(4.3.1.2)\ x_1^{St} \rightarrow x_2^{St} : \Delta x_{induced} = (I - A)^{-1} \Delta f_{lifeline}$$

The calculations for this stage demand additional information about the degree of dependability between the output produced and lifeline services. Unfortunately such information is far more limited and thus the calculations for the additional loss induced by the lifeline system disruption will be omitted for the time being for scenarios I and II.

Step 3. In the second year after the flood production substitution is assumed to take place as a manifestation of economic resilience. This means that lost production of goods in the South Holland during the first year after the flood is overtaken by the same industries found in the rest of the country in the

[9] The programme has been developed at the University of Groningen, the Netherlands. See also *http://www.regroningen.nl/irios/irios.html*.

next year. The degree of substitution depends mainly on the existing spare production capacities of factories. The estimation of those capacities requires special surveying, outside the scope of this paper. We will make some simplifying assumptions concerning substitution and consequently a number of alternative outcomes. We will compute the effect of production transfer for all sectors of 10%, 20%, 50% and 100% of the initial shock.[10] This means that the respective percentage of lost final demand in the province of South Holland in stage 1 will now be regained in the rest of the country.

$$(4.3.1.3)\quad x_2^{St} \rightarrow x_3^{St}: \Delta x_{substitution} = (I - A)^{-1} \Delta f_{substitution}$$

The standard input-output model exercise assumedly overestimates economic loss (see for example Rose and Lim 2002). This stems from unchanged multipliers, which actually should be assumed to decrease as production drops implying that a certain fraction of transactions 'leaks out' of the economy. Another drawback of this scenario is the rigidity of industry production functions. Alternative assumptions will be discussed in the proceeding two scenarios.

4.3.2. Scenario II – Flexible imports model

In order to keep the results of the different scenarios comparable, the sequence of events is assumed to be the same as described earlier in the standard exercise case.
Step 1. As a result of a major direct shock production functions in the province of South Holland change. In order to reflect a higher degree of resilience of the system, the over-proportional lost input purchases from the South Holland are now assumed to be compensated by imports. After a correction of the transactions matrix new indirect multiplier effects are obtained.

$$(4.3.2.1)\quad x_0^{FI} \rightarrow x_1^{FI}: \Delta x_{indirect} = (I - A_{Ms})^{-1} \Delta f_{direct}$$

This will have the following consequences: decreased intermediary production level in the South Holland province and in the rest of the country, decreased employment throughout the country and changed imports. The figures can be expected to be of lower magnitude than those in scenario I, step 1.
Step 2. idem scenario I.
Step 3. Following the initial flood shock, the economy responds with production substitution by the respective industries in the rest of the country during the second year. This shift implies a number of adjustments. Because we work with a bi-regional input-output framework, each input coefficient is split vertically into two

[10] These in production substitution assumptions also will help in providing a comprehensive comparison between the modeling scenarios. Imposing the same initial shock and the same degree of production transfer in each scenario, one is able to clearly distinguish between the strength of the resulting effects.

places of origin: South Holland and the rest of the country. Thus, in the after-flood situation under substitution the increased input requirements of all sectors in the other provinces cannot be proportionally obtained from South Holland as the province recovers. Instead, additional inputs will rather come from producers in the rest of the country.

At the same time a positive final demand impulse is given to the economy (characterised by the new substitution-adjusted structure). This may, in principle, be explained as the increased government expenditures including recovery investment. Hence, final loss figures will be more moderate than the effect of the initial shock. The impact is calculated as follows:

$$(4.3.2.2)\ \ x_2^{FI} \rightarrow x_3^{FI}\!:\!\Delta x_{substitution} = (I - A_{PS})^{-1}\Delta f_{substitution}$$

4.3.3. Scenario III – accounting for 'Bottlenecks'

Contrary to the previous scenario, this is the one for the 'black day' case where the economic system is restricted in response to a vast negative shock.

Step 1. This scenario reflects the result of a production drop as a change in the relationships between economic actors. But in this case the response of the industries in the flood adjacent areas will be much more restricted: we assume here that all the industries in South Holland will be restricted to the level of the sector hit *most heavily* by the disaster. This industry will temporary act as a 'bottleneck' for the rest in the South Holland. This may temporarily happen due to limited access to the area, the time lag needed to establish new contacts to replace lost suppliers and consumers, et cetera. Moreover, the evidence of a sudden large-scale failure of a lifeline can support the emergence of bottlenecks. Therefore, we assume that this scenario approximates the losses incurred by lifeline network disorder. The adjusted input-output table becomes a balanced one through the built up of inventory for the excess supplies and through indebtedness because of increased imports to satisfy final demand. Thus, the trading pattern between the flooded province and the rest of the Netherlands will change, while the production functions will remain constant. We will impose a final demand shock on the new adjusted table:

$$(4.3.3.1)\ \ x_0^{B} \rightarrow x_1^{B}\!:\!\Delta x_{indirect} = (I - A_R)^{-1}\Delta f_{direct}$$

Hereafter, indirect multiplier effects will be obtained. The consequences are expected to be higher than in the previous 'economy resilience' scenario.

Step 2. see step 1.

Step 3. During the recovery phase of this scenario, the initially restricted economic system has more room for expansion. Firstly, the maximum loss clause can be relaxed now as after a year the remaining capacity of South Holland can be restored to the 'natural' distortion level (with bottlenecks removed). Also, the companies in the rest of the country will tend to increase output, thus creating 'production transferability' (this substitution effect will work as described in scenario II). These assumptions call for another adaptation of the economic structure. The re-balancing of the table will happen through inventory and imports adjustments. The impulses of the increased final demand in the rest of the country will be imposed on the renewed table. These impulses can partially reflect extra government spending on recovery programmes.

$$(4.3.3.2)\ x_2^B \rightarrow x_3^B{:}\Delta x_{substitution} = (I - A_{PS})^{-1}\Delta f_{substitution}$$

It's worth noting here that as soon as the economy has more potential to restore it's activity, the recovery will speed up.

4.4. Discussion of Results

Results presented in this section are a fruit of three modelling possibilities. These represent various scenarios for economic response on a large-scale catastrophe. The standard input-output model calculations are given here as a conventional reference point for the other scenarios. Flexible imports scenario suggests an optimistic picture of an economy able to adjust immediately to the sudden distortions. Accounting for 'bottlenecks' scenario models a system, initially paralised by the unexpected shock (indirectly reflecting also lifeline network collapse). In a sense the last model has the highest potential to reflect the possible evolution of disaster aftermath in the most feasible way.

As outlined in the preceding sections, changes in the economy as a result of vast flooding in Central Holland are imposed in an input-output table via an impulse on the final demand and adjustments in the production structure. As a result we are able to trace production level changes throughout the course of calculations. However, note that the main reference category for economic loss evaluation is a change in value added. It acts as a close proxy for a change in GDP, which is also expressed in value-added terms. To refer to the obtained results, consult Appendices 1–3. The tables represent each scenario separately.

To ease the comprehensiveness of the results, Figure 4 is presented here. The graph portrays a vivid picture of possible changes of value added with respect to time for all scenarios, including four substitution alternatives for each of them during the recovery. It is important to note here that although the Graph resembles continuous trends, our analysis is performed for three discreet points in time.[11]

First of all, let us take a look at the order of magnitude for the estimated loss figures. Step one presents the impact brought by the shock. Scenarios I and II suggest, that the initial total loss might overshoot −5%, and the model where the Province of South Holland responds with a highly restricted output to the shock provides with a figure almost twice as that; −9.7% measured in value added terms.

[11] Please, also consider with respect to time that the impacts of steps 1 and 2 (from scenario description, section 4.3) are observed by the end of the first year, and impacts of step 3 – at the end of the second year.

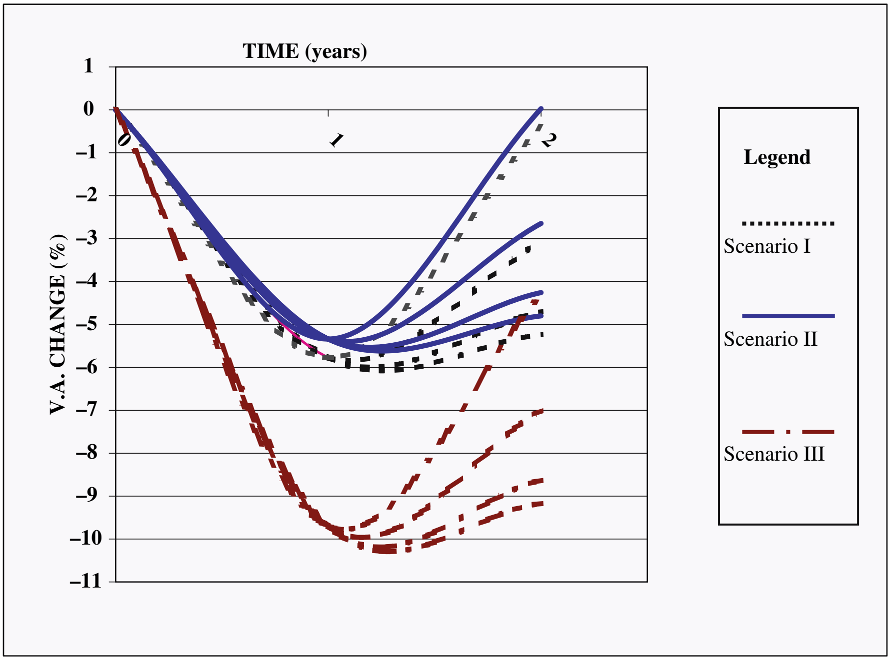

Figure 4. Value added change (%) over time for three scenarios of disaster aftermath

As another general observation one can make is that, the results for scenarios I and II follow each other very closely. Flexible imports scenario is portrays slightly lower loss figures than the ones obtained as a result of standard input-output model use. In turn, the 'bottleneck' scenario presents results that significantly differ from the first two models.

It is of interest to compare the scenarios in observing the effect of various levels of production overtake by the industries in the rest of the country. Whereas a 10% and 20% substitution for all scenarios does not bring much relief, 50% and especially 100% does make a difference. For the standard modelling case, 50% substitution corrects the initial disruption from −5.8% to −3.1%, and a 100% production transfer – up to −0.4%. Similar results are obtained for the adjusted scenario II. For the accounting for 'bottlenecks' model the initial loss estimate is substantially reduced when producers in the provinces outside the flooded region are flexible enough to overtake 100% of the lost output in South Holland. Still, even such extreme behaviour would result in −4.3% loss of value added by the end of the second year compared to the pre-disaster level. Though it seems rather harsh, in the end this scenario might not be that unrealistic. It is the only one that indirectly includes the impact of lifeline disruption.

It may be noted that the differences in the final results stem from the differentials between the scenarios in the first step, where the initial negative flood shock is modelled. Therefore, it can be concluded that the final loss estimate heavily depends on the ability of the economic system to adjust immediately after disaster.

We may draw another conclusion that it is hard for an economy to recover if it operates at full capacity level prior to a disaster. In this case there is no room for production substitution and expansion to take place. Thus, it might trigger the ability of the system to adjust. The same conclusion we may find in Islam (2000, p.159).

The final conclusion to be drawn from the production changes is the economic activity redistribution in the country. As a result of the initial shock and after-phase system adaptations, the relative weight of output in the 'rest of the country' tends to grow compared to the weight of flood-affected South Holland production. This clearly suggests the evolvement of a new structure of the economic system in the entire country.

5. CONCLUSIONS

With regard to methodology development we have made a step forward. We would like to stress the following points:

1) The problem of double-counting poses a significant threat of overestimating the overall damage. We expect this possible confusion to be resolved if one explicitly discriminates between stock and flow measurements. Direct damage based on flow estimation gives sound grounds for safe business interruption and indirect damage assessments.
2) The standard input-output model is given more flexibility: it has been adapted for modelling the needs of a large-scale flooding disaster. Such crucial elements as 'production bottlenecks', 'substitution effects' and 'time dimension' are included into the analysis of the indirect effects on an economy.
3) Pivotal point of the adaptations performed is the assumption about the technology change as a result of a vast devastating flood and its consequences. Thus, we are modelling an economy that tends to adjust continuously.
4) Practical problems faced during the empirical estimation for the case of a large-scale flooding in the Province of South Holland involve the joining of data between different data sets (geographically referenced GIS and bi-regional input-output tables, which reflect the structure of economic relations). Providing the employment data with the additional spatial dimension forms the core element of coupling different data sets in our research.
5) Empirical economic loss calculations for our case study were performed for the initial shock and the recovery phase. Standard modelling is compared with two alternative input-output table transformation models. As a result it could be shown that a significant difference between the final loss estimates depends substantially on the initial response of the economy to a shock, as well as on the transferability level within the system.
6) Further possibilities for methodology extensions and empirical applications should preferably involve software development. More is to be done in the formalisation of the input-output table transformations. Next steps need to be based on additional information concerning induced lifeline disruption and production substitution possibilities. This most likely will bring significant downward corrections to the total economic loss estimates.

APPENDIX 1 MODELLING RESULTS: SCENARIO I [STANDARD EXERCISE]*

		Scenario 1					
			value before the impulse	Direct impulse	Indirect effect	Total effect of the impulse	value after the impulse
STEP 1: Initial shock to the economy after the flood		*Production (South Holland)*	*235341*	*-40679*	*-9037*	*-49716*	*186425*
		Production (rest of the country)	*790058*	*0*	*-8491*	*-8491*	*781567*
		Total production	1025399	-40679	-17528	-58207	967992
		% production change (w.r.t. pre-disaster output)					-5,60
		% prod. change during the step				-5,68	
		Total value added	**593216**			-34222	**558877**
		% value added change (w.r.t. pre-disaster v.a.)					-5,77
		% v.a. change during the step				-5,77	
STEP 3: Recovery (production substitution scenarios)	10%	*Production (South Holland)*	*186425*	*0*	*199*	*199*	*186624*
		Production (rest of the country)	*781567*	*4067*	*1531*	*5598*	*787165*
		Total production	967992	4067	1730	5797	973789
		% production change (w.r.t. pre-disaster output)					-5,03
		% prod. change during the step				0,60	
		Total value added	**558877**			3185	**562062**
		% value added change (w.r.t. pre-disaster v.a.)					-5,23
		% v.a. change during the step				0,57	
	20%	*Production (South Holland)*	*186425*	*0*	*401*	*401*	*186826*
		Production (rest of the country)	*781567*	*8140*	*3072*	*11212*	*792779*
		Total production	967992	8140	3469	11609	979605
		% production change (w.r.t. pre-disaster output)					-4,47
		% prod. change during the step				1,20	
		Total value added	**558877**			6376	**565253**
		% value added change (w.r.t. pre-disaster v.a.)					-4,70
		% v.a. change during the step				1,14	
	50%	*Production (South Holland)*	*186425*	*0*	*998*	*998*	*187423*
		Production (rest of the country)	*781567*	*20339*	*7674*	*28013*	*809580*
		Total production	967992	20339	8672	29011	997003
		% production change (w.r.t. pre-disaster output)					-2,77
		% prod. change during the step				3,00	
		Total value added	**558877**			15928	**574805**
		% value added change (w.r.t. pre-disaster v.a.)					-3,08
		% v.a. change during the step				2,85	
	100%	*Production (South Holland)*	*186425*	*0*	*1998*	*1998*	*188423*
		Production (rest of the country)	*781567*	*40679*	*15342*	*56021*	*837588*
		Total production	967992	40679	17340	58019	1026011
		% production change (w.r.t. pre-disaster output)					0,06
		% prod. change during the step				5,99	
		Total value added	**558877**			31858	**590735**
		% value added change (w.r.t. pre-disaster v.a.)					-0,40
		% v.a. change during the step				5,70	

* in millions of guilders, basic prices of 1992. [1 Euro = 2.21 Guilders]

APPENDIX 2 MODELLING RESULTS: SCENARIO II [FLEXIBLE IMPORTS MODEL]*

		Scenario 2	value before the impulse	Direct impulse	Indirect effect	Total effect of the impulse	value after the impulse
STEP 1: Initial shock to the economy after the flood		*Production (South Holland)*	235341	-40679	-16599	-57278	178063
		Production (rest of the country)	790058	0	-8440	-8440	781618
		Total production	1025399	-40679	-25039	-65718	959681
		% production change (w.r.t. pre-disaster output)					-6,41
		% prod. change during the step				-6,41	
		Total value added	**593216**			-31774	561442
		% value added change (w.r.t. pre-disaster v.a.)					-5,34
		% v.a. change during the step				-5,36	
STEP 3: Recovery (production substitution scenarios)	10%	*Production (South Holland)*	178063	0	555	555	178618
		Production (rest of the country)	781618	4067	3295	7362	788980
		Total production	959681	4067	3855	7922	967598
		% production change (w.r.t. pre-disaster output)					-5,64
		% prod. change during the step				0,83	
		Total value added	**561442**			3179	**564621**
		% value added change (w.r.t. pre-disaster v.a.)					-4,80
		% v.a. change during the step				0,57	
	20%	*Production (South Holland)*	178063	0	757	757	178820
		Production (rest of the country)	781618	8140	6628	14768	796386
		Total production	959681	8140	7380	15520	975206
		% production change (w.r.t. pre-disaster output)					-4,89
		% prod. change during the step				1,62	
		Total value added	**561442**			6364	**567806**
		% value added change (w.r.t. pre-disaster v.a.)					-4,26
		% v.a. change during the step				1,13	
	50%	*Production (South Holland)*	178063	0	1333	1333	179396
		Production (rest of the country)	781618	20339	16779	37118	818736
		Total production	959681	20339	18119	38458	998132
		% production change (w.r.t. pre-disaster output)					-2,66
		% prod. change during the step				4,01	
		Total value added	**561442**			15915	**577357**
		% value added change (w.r.t. pre-disaster v.a.)					-2,65
		% v.a. change during the step				2,83	
	100%	*Production (South Holland)*	178063	0	2310	2310	180373
		Production (rest of the country)	781618	40679	34295	74974	856592
		Total production	959681	40679	36607	77286	1036965
		% production change (w.r.t. pre-disaster output)					1,13
		% prod. change during the step				8,05	
		Total value added	**561442**			31852	**593294**
		% value added change (w.r.t. pre-disaster v.a.)					**0,03**
		% v.a. change during the step				5,67	

* in millions of guilders, basic prices of 1992. [1 Euro = 2.21 Guilders]

APPENDIX 3 MODELLING RESULTS: SCENARIO III [ACCOUNTING FOR 'BOTTLENECK' MODEL]*

		Scenario 3	value before the impulse	Direct impulse	Indirect effect	Total effect of the impulse	value after the impulse
STEP 1: Initial shock to the economy after the flood		*Production (South Holland)*	235341	-40679	-18530	-59209	176132
		Production (rest of the country)	790058	0	-20796	-20796	769262
		Total production	1025399	-40679	-39326	-80005	945394
		% production change (w.r.t. pre-disaster output)					-7,80
		% prod. change during the step				-7,80	
		Total value added	593216			-57565	535651
		% value added change (w.r.t. pre-disaster v.a.)					-9,70
		% v.a. change during the step				-9,70	
STEP 3: Recovery (production substitution scenarios)	10%	*Production (South Holland)*	176132	0	503	503	176635
		Production (rest of the country)	769262	4067	3422	7489	776751
		Total production	945394	4067	3925	7992	953386
		% production change (w.r.t. pre-disaster output)					-7,02
		% prod. change during the step				0,85	
		Total value added	535651			3188	538839
		% value added change (w.r.t. pre-disaster v.a.)					-9,17
		% v.a. change during the step				0,60	
	20%	*Production (South Holland)*	177132	0	759	759	177891
		Production (rest of the country)	768262	8140	6712	14852	783114
		Total production	945394	8140	7471	15611	961005
		% production change (w.r.t. pre-disaster output)					-6,28
		% prod. change during the step				1,65	
		Total value added	535651			6385	542036
		% value added change (w.r.t. pre-disaster v.a.)					-8,63
		% v.a. change during the step				1,19	
	50%	*Production (South Holland)*	177132	0	1363	1363	178495
		Production (rest of the country)	768262	20339	16914	37253	805515
		Total production	945394	20339	18277	38616	984010
		% production change (w.r.t. pre-disaster output)					-4,04
		% prod. change during the step				4,08	
		Total value added	535651			15965	551616
		% value added change (w.r.t. pre-disaster v.a.)					-7,01
		% v.a. change during the step				2,98	
	100%	*Production (South Holland)*	177132	0	2499	2499	179631
		Production (rest of the country)	768262	40679	34372	75051	843313
		Total production	945394	40679	36871	77550	1022944
		% production change (w.r.t. pre-disaster output)					-0,24
		% prod. change during the step				8,20	
		Total value added	535651			31966	567617
		% value added change (w.r.t. pre-disaster v.a.)					-4,32
		% v.a. change during the step				5,97	

* in millions of guilders, basic prices of 1992. [1 Euro = 2.21 Guilders]

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