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Modeling Imbalanced Economic Recovery Following a Natural Disaster Using Input-Output Analysis

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Input-output analysis is frequently used in studies of large-scale weather-related (e.g., Hurricanes and flooding) disruption of a regional economy. The economy after a sudden catastrophe shows a multitude of imbalances with respect to demand and production and may take months or years to recover. However, there is no consensus about how the economy recovers. This article presents a theoretical route map for imbalanced economic recovery called dynamic inequalities. Subsequently, it is applied to a hypothetical postdisaster economic scenario of flooding in London around the year 2020 to assess the influence of future shocks to a regional economy and suggest adaptation measures. Economic projections are produced by a macro econometric model and used as baseline conditions. The results suggest that London's economy would recover over approximately 70 months by applying a proportional rationing scheme under the assumption of initial 50% labor loss (with full recovery in six months), 40% initial loss to service sectors, and 10–30% initial loss to other sectors. The results also suggest that imbalance will be the norm during the postdisaster period of economic recovery even though balance may occur temporarily. Model sensitivity analysis suggests that a proportional rationing scheme may be an effective strategy to apply during postdisaster economic reconstruction, and that policies in transportation recovery and in health care are essential for effective postdisaster economic recovery.

KEY WORDS: Disaster; dynamic inequalities; input-output analysis; London flooding; rationing schemes

1. INTRODUCTION

Some recent large-scale disasters such as the 2003 heat wave that struck Paris and other European cities, the 2004 Indian Ocean earthquake leading to the Asian tsunami, Hurricane Katrina in New Orleans (USA) in 2005, Cyclone Nargis in Myanmar in 2008, and the 2008 Sichuan earthquake in China show the urgency of understanding and then preparing for such environmental hazards, including understanding their impacts on the economy.(1) Research indicates that economic losses caused by such events have been on the rise in last few decades.(2) With the concentration of population and assets, metropolitan areas are particularly vulnerable to such disasters.

Temporal properties such as magnitude and duration of extreme climatic events determine the extent of initial damage inflicted and have significant influence on the adaptive capacity of individuals, households, and therefore an economy.(3) The duration of an event, including the length of recovery, is very important in estimating economic costs of a climate-change-related disaster.(4,5) Studies(6–8) have appeared in recent years in postdisaster economic modeling aiming to better understand the

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consequences of environmental disasters for a regional economy and to develop prevention and recovery strategies.

The article presents a model for assessing the economic impacts of disasters, organized as follows. In Section 2, a literature review of recent development in risk damage valuation is presented. In Section 3, a series of dynamic inequalities are introduced to provide a theoretical basis for modeling imbalanced economic recovery. Section 4 applies these inequalities to a hypothetical postdisaster economic scenario occurring in London around 2020. In Section 5, a U.K. multisectoral dynamic model is used to project predisaster economic conditions and provide the main baseline data required by the scenario. Section 6 presents simulation results on production and demand inequalities. A sensitivity analysis is carried out in Section 7, which mainly focuses on different disaster scales, rationing schemes, and alternative exogenous labor and household consumption recovery paths. Finally, Section 8 summarizes the findings and proposes directions for further research. The case study and key assumptions are provided in the Appendix.

2. RECENT DEVELOPMENT OF RISK DAMAGE VALUATION

A number of well-known modeling methodologies, including computable general equilibrium (CGE), econometrics, and input-output (IO) analysis, are frequently used to assess economic recovery following damage. However, no distinct advantages of any are evident across all applications. For example, CGE is considered to be overly optimistic on market flexibility and overall substitution tendencies,(9) while IO analysis does not take into account productive capacity and producer and consumer behaviors.(7) Econometric models are more prevalent at the national level, while IO models are the major tools of regional impact analysis.(10) Moreover, econometric models, which are based on time-series data that may not include any major disasters, appear ill-suited for disaster impact analysis(1) and cannot easily distinguish between direct and indirect effects.(11) On the other hand, such models are statistically rigorous, which can provide a basis for stochastic estimates and forecasting. IO analysis is grounded in the technological relationships of production and provides a full accounting for all inputs into production,(9) which is in contrast to some large econometric models that express quantities only in terms of primary factors of production. Moreover, IO analysis is a powerful tool to assess the economic effect of a natural catastrophe at regional and sectoral levels through effects on intermediate consumption and demand. Although IO analysis is mainly a model of production, it is fully capable of analyzing demand by households and other institutions affected by a disaster.(12) Also, the simplicity of IO analysis and the ability to integrate it with engineering models add to its popularity.

Existing literature(1,11,13–19) suggests that there is no generally accepted methodology for the representation of postdisaster economic development, and no uniform way in which economic agents will adjust their actions during a period of economic imbalance. Steenge and Bočkarjova(6,8) suggest an approach by connecting a closed IO table with an event accounting matrix.(15) They assume that postdisaster economic recovery will have two steps to restore predisaster conditions: the first is to reach "as fast as possible" the targeted output proportions and the second is to bring the economy back to the predisaster level of operation. However many situations have demonstrated that an imbalance may persist during a postdisaster period, requiring that economic agents adapt themselves in a dynamic manner. Moreover, the basic equation does not solve the dynamic, temporal change in the postdisaster economy.

Hallegatte(7) applies IO analysis to the landfall of Katrina in Louisiana by taking into account changes in production capacity due to productive losses and adaptive behavior in the aftermath of a disaster. However, the impacts of housing destruction and labor constraints on production capacity are neglected, each of which critically influence the recovery process. Haimes, Jiang, and Santos(17,20) provide an alternative IO approach—the inoperability input–output model (IIM)—to assess direct and indirect economic impacts based on the demand-side Leontief equation with perturbation and inoperability vectors. The term "inoperability" is used to connote the level of a system's dysfunction, expressed as a percentage of its "as-planned" production capacity available at any point in time. IIM has been featured in economic interdependency analysis with different applications such as analysis of workforce disruptions caused by pandemics(21) and economic impacts of terrorism.(20) However, such an approach does not take into consideration supply bottlenecks(7) and demand constraints. Moreover, it only captures peripheral time-varying features (e.g., sector resilience through a resilience coefficient matrix(21)) in its dynamic IIM,[22–24] while some more important time-varying features such as demand behavior adaptation, labor force change, and import and export dynamics are not fully considered.

Von Neumann growth theory asserts that an imbalanced economic setting following a disaster will seek a return of balance between economic agents before an economy can continue to grow.[8] However, this is not entirely true empirically. A postdisaster economy often keeps an imbalanced state of development during the recovery period, as reflected in the 2003 heat wave that struck Paris and other European cities, Hurricane Katrina in New Orleans, and the 2008 Sichuan earthquake in China. Moreover, current studies rarely reflect the influence of hypothetical future shocks to a regional economy, which is vital for decision planning.

Based on the stated strengths and limitations of existing methods and analyses, this article adopts an IO analysis linked to a macro-econometric model (the U.K. multisectoral dynamic model or MDM[25]), adding a temporal dimension to analyze changes in a regional economy and assess economic costs, vulnerability, and resilience of the region during the period of recovery following a disaster. In the study, a monthly IO model is constructed through a series of dynamic inequalities, followed by integrating the IO model with an event accounting matrix to assess recovery of a postdisaster economy along an imbalanced recovery route. The model is applied to assess London's economic adaptability in the aftermath of a hypothetical flooding event around 2020. The dynamics of final demand categories, labor force recovery, and import-export adjustments during the postdisaster period in response to the inequalities are developed.

3. THE BASIC DYNAMIC INEQUALITIES

This section presents an input-output basic dynamic inequalities (BDI) model capable of assessing the impact of a natural disaster at the level of a regional economy, accounting for interactions between industries through demand and supply of intermediate consumption of goods with circular flow—a set of inputs that should be in balance, given certain restrictions, with a set of outputs that subsequently become a set of inputs in the next temporal round. No prior economic balance will be assumed during the period of recovery in the model.

Regarding the mathematical symbols and formulae, matrices are represented by bold capital letters (e.g., $\mathbf{X}$); vectors by bold lowercase (e.g., $\mathbf{x}$), and scalars by italic lowercase (e.g., x); by default, vectors are column vectors, with row vectors being obtained by transposition (e.g., $\boldsymbol{x}'$); a conversion from a vector (e.g., $\mathbf{x}$) to a diagonal matrix is expressed as the bold lowercase letter with a circumflex (i.e., $\hat{\mathbf{x}}$); and the operators ".*" and "./" are used to express element-by-element multiplication and division of two vectors, respectively. The two operators can be converted into mathematical expressions. For example, given two vectors $\mathbf{x}$ and $\boldsymbol{y}$ with nonzero elements, the conversions are:

$$\mathbf{x}.*\mathbf{y} = \hat{\mathbf{x}} \times \mathbf{y} \tag{a}$$

$$\mathbf{x}./\mathbf{y} = (\hat{\mathbf{y}})^{-1} \times \mathbf{x}. \tag{b}$$

Assume a regional economy consisting of n industries that exchange intermediate consumption goods and services in order to sustain the production processes, and final demand categories that include final consumption goods and services for local household, government, fixed investment, and export. This economy is struck by a natural disaster, which initially damages household physical assets, industrial capitals and stocks, and the transportation system, thereby affecting people traveling.

The input-output BDI model is derived from a standard IO model that reflects a detailed flow of goods and services between producers and consumers. All economic activities are assigned to production and consumption sectors. An economy with n sectors in the predisaster condition can be presented in the following standard IO relationship:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f}, \tag{1}$$

where $\mathbf{x}$ represents sectoral production output, $\mathbf{f}$ represents final demand, and $\boldsymbol{A}$ is matrix of the technical coefficients.

A standard IO model is a solely demand-driven, open model. In the postdisaster period, however, limitations in supplies become important constraints for production capacity. On the other hand, Leontief closed models allow for tracking the supply and demand of each individual good and those that are considered as primary inputs such as labor in an open model. Let us introduce a labor constraint to Equation (1):

$$\begin{bmatrix} \mathbf{A} & \mathbf{f}/l \\ \mathbf{l}' & 0 \end{bmatrix} \begin{pmatrix} \mathbf{x} \\ l \end{pmatrix} = \begin{pmatrix} \mathbf{x} \\ l \end{pmatrix} \tag{2}$$

or

$$\mathbf{Mq} = \mathbf{q},\ \text{where}\ \mathbf{M} = \begin{bmatrix} \mathbf{A} & \mathbf{f}/l \\ \mathbf{l}' & 0 \end{bmatrix}\ \text{and}\ \mathbf{q} = \begin{pmatrix} \mathbf{x} \\ l \end{pmatrix} \tag{3}$$

with

$$l = \mathbf{l}'\mathbf{x}, \tag{4}$$

where l is a scalar of total regional employment, while $\mathbf{l}'$ is a row vector of direct labor input coefficients. Equation (4) describes an economy in equilibrium with a closed Leontief model, which is the so-called basic equation.[(8)] The left-hand side of Equation (3) stands for the totality of inputs, and the right-hand side for the totality of outputs in the economy.

Let us introduce time dynamics and a damage fraction (i.e., event accounting matrix) into the equations step by step, first:

$$\mathbf{x}_{td}^t = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}^t, \quad (t > 0) \tag{5.1}$$

$$\text{or, } \mathbf{x}_{td}^t \approx \mathbf{A}\left(\mathbf{I} - \mathbf{\Gamma}^t\right)\mathbf{x}^0 + \mathbf{f}^t, \tag{5.2}$$

where in Equation (5.1) $\mathbf{x}_{td}^t$ simulates the degraded total demand determined by final demand $\mathbf{f}^t$ over time, and t refers to a time step (in this article we denote the predisaster time as $t = 0$, and $t = 1$ as the first period immediately after the disaster). In Equation (5.2), $\mathbf{x}_{td}^t$ is calculated based on the intermediate demand met by the current production capacity and total final demand.[3]However, the equation needs to be balanced between $\mathbf{A}\left(\mathbf{I} - \mathbf{\Gamma}^t\right)\mathbf{x}^0$ and $\mathbf{f}^t$.

In Equations (5.1) and (5.2), $\boldsymbol{I}$ is an $n \times n$ identity matrix. The matrix $\mathbf{\Gamma}$ is the damage fraction matrix—an n dimensional diagonal matrix which changes with time:

$$\mathbf{\Gamma}^t = \begin{pmatrix} \gamma_1^t & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \gamma_n^t \end{pmatrix}. \tag{6}$$

Meantime, let us introduce dynamics into Equation (4):

$$\mathbf{x}_l^t = \mathbf{l}_e^t./\mathbf{l},\ \text{where}\ \mathbf{l}_e^t = \left(1 - \gamma_{n+1}^t\right)\mathbf{l}_e^0, \tag{7}$$

where $\mathbf{x}_l^t$ simulates the degraded labor production capacity, $\mathbf{l}_e^t$ represents the employment in sectors at time t, and the parameter $\gamma_i^t\ (0 \leq \gamma_i \leq 1; 1 \leq i \leq n+1)$ indicates the fraction of the production capacity lost in industry i $(1 \leq i \leq n)$ as shown in Equation (6), or in labor $(i = n+1)$ at the time step t as shown in Equation (7). Here, we assume that the impact of employment loss on each sector is equally distributed. Equations (5) and (7) are constrained by the following equations at each time step,

$$\mathbf{x}_{tp}^t = l(\mathbf{I} - \mathbf{\Gamma}^t)\mathbf{x}^0 \tag{8}$$

$$\mathbf{Mq}^{*(t)} = \mathbf{q}^{*(t)},\ \text{where}\ \mathbf{q}^{*(t)} = \begin{pmatrix} \mathbf{x}^{*(t)} \\ l^{*(t)} \end{pmatrix} \tag{9}$$

$$\mathbf{q}^{*(t)} = \begin{pmatrix} \mathbf{x}^{*(t)} \\ l^{*(t)} \end{pmatrix} \leftarrow \mathbf{q}^{(t)} = \begin{pmatrix} \mathbf{x}_{tp|td|l}^t \\ l_{tp|td|l}^t \end{pmatrix}, \tag{10}$$

where $\mathbf{x}_{tp}^t$ simulates the degraded total production. Equation (9) refers to a balanced economy in a closed model, while the balance (i.e., $\mathbf{q}^{*(t)}$) can be calculated by Equation (10) through $\mathbf{q}^{(t)}$. Here, we use $\mathbf{q}^{*(t)}$ to represent a balanced total output and labor force, distinct from $\mathbf{q}^{(t)}$, which represents an imbalanced input-output condition. $\mathbf{x}_{tp|td|l}^t$ and $l_{tp|td|l}^t$ represent the balances of total output and labor as required between total production capacity, total demand, and labor production capacity at time step t. As there are constraints during the recovery between these factors (e.g., the labor production capacity may not meet or may exceed the capital production capacity), a balance is needed. There are many ways (represented by the label "$\leftarrow$" in Equation (10) to adapt $\mathbf{q}^{(t)}$ to a balanced input-output condition. The article introduces two ways to achieve it in Section 4.5.

From the equations shown earlier, there exist a few inequalities at each time step. Let us consider a condition at time step t during the recovery. Then, the inequalities are as shown below:

$$\begin{cases} \mathbf{x}_{td}^t \neq \mathbf{x}_{tp}^t \\ \mathbf{x}_{td}^t \neq \mathbf{x}_l^t \\ \mathbf{x}_{tp}^t \neq \mathbf{x}_l^t \end{cases} \tag{11}$$

and

$$\mathbf{Mq}_{\text{deg}}^t \neq \mathbf{q}_{\text{deg}}^t, \tag{12}$$

where $\mathbf{q}_{\text{deg}}^t$ represents the degraded total economic output and the labor force within a closed model at time t. The condition holds unless $\mathbf{q}_{\text{deg}}^t$ is proportional to $\mathbf{q}^0$, which is the case when the economy is shrinking proportionally in all sectors. Even though balance or proportion may hold at some time steps, the dynamic inequalities may still appear at subsequent time steps as total production capacity, final

[3]Under certain economic circumstances and assumptions, the $\boldsymbol{A}$ matrix may also change over time, which is not considered in this article.

demand, and labor capacity vary disproportionately. In practice, the economy only has a "tendency" during the recovery period to move back toward predisaster conditions.

The series of inequalities introduced is to provide a general framework for modeling postdisaster economic recoveries; they are not intended to give solutions to simulate the dynamics of the specific factors such as total production, final demand behaviors, and labor recovery. In specific applications of the model, it is left to analysts to specify the dynamics of these economic actors pertaining to specific postdisaster circumstances. Imports and exports during the disaster and recovery period are not only affected by the severity of a disaster, especially reflected in damage to the transportation infrastructure, but also by disaster aid policies and actions. The following sections implement the framework and also simulate the dynamics of those economic factors mentioned earlier using a hypothetical case of storm damage in London in 2020.

4. MODELING THE RECOVERY OF LONDON AFTER FLOODING

Urban areas are spatial concentrations of vulnerability to climate change. Here, let us assume that London is stricken by a flooding incident from the River Thames around 2020, which may be caused by a combination of on-tidal flooding from the Thames, fluvial flooding from tributaries that flow into the river, and surface water flooding resulting from excessive rainfall. London's economic structure is severely disrupted by the flooding, which is reflected in labor and production capacity losses and final demand reductions. Details of the assumed damage magnitude are given in the following sections. If one views the economy as a system of circular flow interrelations among production and consumption, then the interrelations are broken suddenly by the incident and a number of imbalances occur in the London economy's supply-demand relationships during the period of recovery. This section focuses on modeling economic consequences of the hypothetical disaster, including the economic recovery process and the possible response strategies based on the BDI framework introduced previously.

4.1. Modeling Process

In the modeling we assume that the labor recovery path (expressed as $\mathbf{l}_e^t$) is defined exogenously. The BDI model of London simulates the total final consumption adaptation process (expressed as $\mathbf{f}^t$) based on consideration of a long-term tendency back to the predisaster economic condition and a short-term tendency toward a balanced economy. Household demand usually accounts for more than half of total final demand. Let us assume that the household consumption pattern changes during the disaster and subsequent recovery period, that household demand will therefore have a sudden drop, and that it will increase gradually thereafter but not exceed the level of the predisaster condition. Immediately following the disaster, households will switch their consumption patterns to focus on basic goods and services such as food, water, clothing, and health care, for which government and civil society can usually ensure a sustainable supply even though local production may not be sufficient. We also introduce a distinction between sectors according to whether the substitution of local production by external providers is or is not possible (e.g., one cannot substitute an external provider for electricity or local transportation).

In the study, the recovery process is modeled on a monthly basis with three computational steps at each time interval. First, labor loss is captured by the percentage of labor not available for traveling, the percentage of labor delayed for work because of transport damage and corresponding hours of delay in travel. The labor production capacity— $\mathbf{x}_l^t$—is calculated based on Equation (7). The capital production capacity—$\mathbf{x}_{tp}^t$—during recovery is captured by the damage demand through the magnitude of local production. It corresponds to dynamic Equation (8). Then, the production capacities of surviving labor and capital are compared with the current total demand—$\mathbf{x}_{td}^t$—resulting from the final demand change, allowing determination of how much could be locally produced based on constraints between the three factors (reflected in Equations (9) and (10)). A rationing scheme (either a proportional rationing, or a priority system, or a mix of these) is applied to the intermediate consumption and a new total production is calculated. Third, if the three elements (new total production capacity; total demand and labor production capacity; and predisaster total production) are met, the economy has recovered from the postdisaster conditions; otherwise, a new total demand is calculated based on the new total final demand adjustment (corresponding to Equation (5)). Then the three steps repeat with a new time step and the labor and capital production capacities are recalculated. A detailed diagram for the recovery, with components such as the final demand behavior adjustment equation and import availability computation, is given in Fig. A1. The following subsections are further illustrations of essential components involved in the modeling process.

4.2. Reconstruction Demands

Let us consider that the flooding occurs at $t = 0$, and thereafter the economy recovers gradually over time ($t = 1, 2, \ldots$). In this example, the disaster causes an amount of industrial capital damage—$\mathbf{d}^1_{\text{cap}}$—and households, housing and equipment damage—$\mathbf{d}^1_{hh}$ (in sectors). Let us assume that these damages will all be repaired or replaced throughout the entire postdisaster period. Repair of this damage will lead to additional demands—$\mathbf{f}^1_{\text{rec}}$:

$$\mathbf{f}^1_{\text{rec}} = \mathbf{d}^1_{\text{cap}} + \mathbf{d}^1_{hh}. \tag{13}$$

Here, $\mathbf{d}^1_{\text{cap}}$ and $\mathbf{d}^1_{hh}$ are damages immediately after the flooding and are $n \times 1$ vectors. The Leontief equation can be rewritten in terms of the damages for industry i as:

$$\mathbf{x}^1(i) = \sum_j \mathbf{A}(i, j)\,\mathbf{x}^1(j) + \begin{cases} \mathbf{f}^1_{hh}(i) \\ \mathbf{f}^1_{\text{gov}}(i) \\ \mathbf{f}^1_{\text{cap}}(i) \\ \mathbf{f}^1_{\text{exp}}(i) \\ \mathbf{f}^1_{\text{rec}}(i). \end{cases} \tag{14}$$

As shown in the equation, industry i consists of two sets of demand: intermediate demand and final demand. The final demand—$\mathbf{f}^1$—consists of household consumption—$\mathbf{f}^1_{hh}$, governmental expenditures—$\mathbf{f}^1_{\text{gov}}$, fixed capital formations—$\mathbf{f}^1_{\text{cap}}$, exports—$\mathbf{f}^1_{\text{exp}}$— and the reconstruction demand—$\mathbf{f}^1_{\text{rec}}$, which is zero prior to the disaster.

4.3. Labor and Production Capacity

The BDI model's focus is on simulating how the economy meets core tasks such as fulfillment of consumer demand. In the aftermath of a disaster, industries may be unable to produce enough to satisfy the demand due to (i) insufficient production capacity caused by the loss of capital, (ii) insufficient intermediate supply from other industries, or (iii) insufficient primary inputs such as the loss of labor, as reflected by Equations (5.1), (7), and (8). A disaster may affect these categories differently. For example, flooding could cause labor loss. In this case, a firm's production capacity decreases due to lack of a primary input—the workforce—to perform production activities. Alternatively, the major loss may be from industrial capital damage rather than labor. The difference causes the inequalities over time as shown in Equations (11) and (12).

Labor shortage in the postdisaster period is one of the important supply constraints for economic recovery. In the postdisaster period, the labor production capacity reduction caused by the loss of life and time delay for work-related travel is captured by $\mathbf{x}^t_l$ and $\mathbf{l}^t_e$. Let us assume every laborer works for 8×22 hours per month. If the amount of extra hours for each laborer spent on traveling in the month i of the postdisaster replaces working hours and is captured by o_i, and the percentage of labor affected is p_i, then the relative percentage of labor loss in the month is identified by $p_i \times o_i / (8 \times 22)$. Here we assume that the labor loss and additional travel time are provided exogenously, and that they return to the predisaster condition linearly within six months (see Table A1). Then the labor production capacity can be calculated based on Equation (7).

The maximum production capacity of industry i is set equal to the predisaster total output $\mathbf{x}^0(i)$. Production capacity is decreased immediately after the flooding. The degraded capacity $\mathbf{x}^1_{\text{deg}}(i)$ serves as an initial condition for economic recovery resulting from the repair or replacement of productive capital and stock. Let us assume the capital remaining will function fully and is determined by the amount of surviving productive capital in percentage terms, represented here by the matrix $\mathbf{\Gamma}$ as shown in Equation (8). The production capacity increases both through local production and imports at each time step, which is again influenced by the rationing strategy selected by actors.

In the study, the "overproduction" effect is not modeled because that effect usually happens in manufacturing sectors, while London's economy is dominated by service sectors. For this exercise, we assume that the disaster will not influence the labor productivity of an industry, although it may lead to the loss of employment due to the reduced production capacity.

4.4. Rationing Scheme

When industries have limited capacity, unable to fulfill both intermediate and final consumption demand, a rationing scheme is applied to prioritize the allocation of commodities. In the present modeling, two different rationing schemes are considered: a "priority" scheme and a "proportional" scheme. Here let us assume priorities are distributed between categories of "Intermediate Demand—$\sum_j \mathbf{A}(i, j)\,\mathbf{x}(j)$," "Final Demand for Industries and Households Reconstruction—$\mathbf{f}_{\text{rec}}(i)$," "Households Demand—$\mathbf{f}_{\text{hh}}(i)$," "Governmental Demand—$\mathbf{f}_{\text{gov}}(i)$," "Fixed Capital Formation—$\mathbf{f}_{\text{cap}}(i)$," and "Exports—$\mathbf{f}_{\exp}(i)$," and that priority for allocation of production is always given to intermediate demand for both schemes. This assumption is justified by the fact that in reality business-to-business relationships are usually deeper than business-to-household relationships, and so a business often favors business clients over household clients.[7]

If an industry has satisfied the intermediate demand of other industries, the remaining production will be distributed among $\mathbf{f}_{\text{rec}}(i)$, $\mathbf{f}_{\text{hh}}(i)$, $\mathbf{f}_{\text{gov}}(i)$, and $\mathbf{f}_{\exp}(i)$ in proportion to the predisaster allocation in the case of proportional rationing, or prioritized and assigned to them in a sequence (defined exogenously) in the case of the priority scheme. The proportion is calculated based on two equations:

$$\left(\mathbf{x}_{tp}^{t} - \mathbf{A} * \mathbf{x}_{tp}^{t}\right) .* \mathbf{f}_{k}^{0}. \Big/ \left(\sum^{\mathbf{f}_k^0} + \mathbf{f}_{\text{rec}}^{t}\right), \qquad (15.1)$$

$$\left(\mathbf{x}_{tp}^{t} - \mathbf{A} * \mathbf{x}_{tp}^{t}\right) .* \mathbf{f}_{\text{rec}}^{t}. \Big/ \left(\sum^{\mathbf{f}_k^0} + \mathbf{f}_{\text{rec}}^{t}\right), \qquad (15.2)$$

where k refers to the subscripts hh, gov, cap, and exp; $\left(\mathbf{x}_{tp}^{t} - \mathbf{A} * \mathbf{x}_{tp}^{t}\right)$ refers to the production left after satisfies the intermediate demand; and $\sum^{\mathbf{f}_k^0}$ refers to the total final demand in the predisaster period. Equation (15.1) calculates the proportions distributed to the household, government, capital formation, and export, respectively, while Equation (15.2) calculates the actual consumption due to reconstruction over time.

The priority scheme distributes the remaining production based on a prior sequential set of preferences. For example, if one sets a priority ranking as "Final Demand for Industries and Households Reconstruction—$\mathbf{f}_{\text{rec}}(i)$" > "Households Demand—$\mathbf{f}_{\text{hh}}(i)$" > "Governmental Demand—$\mathbf{f}_{\text{gov}}(i)$" > "Fixed Capital Formation—$\mathbf{f}_{\text{cap}}(i)$" > "Exports—$\mathbf{f}_{\exp}(i)$," then goods will be distributed so as to satisfy the reconstruction demand first. Any goods left over will then be used to satisfy households' demand, and so on in order of declining preference.

In the following sections of the modeling, the proportional rationing scheme has been extensively used. Only in the sensitivity test are other rationing schemes applied. The justification of this choice is illustrated in the sensitivity analysis section.

4.5. Consumption Behavior, Import, and Recovery

In the modeling, consumption demand for luxury goods is assumed to be halved immediately after the disaster (see the sectoral detail in Table A2, expressed by vector μ^0). The recovery process is influenced both by the long-term tendency to go back to the predisaster economic condition and short-term tendency towards a balance between total production capacity and total demand at the current time step. The short-term tendency represents a noise factor to the long-term recovery. The dynamic household consumption recovery equation is given below:

$$\mathbf{f}_{\text{hh}}^{t} = (\mu^0 + s * \mathbf{d}_1^t + r * \mathbf{d}_2^t) .* (\mathbf{V} * \mathbf{c}^0), \qquad (16)$$

where $(\mu^0 + s * \mathbf{d}_1^t + r * \mathbf{d}_2^t)$ models the recovery of household demand damage (a parameter vector similar to the EAM, $\mathbf{\Gamma}^t$) over time, vector $\mathbf{c}^0$, and matrix $\mathbf{V}$ represent the predisaster total household expenditure on products and a converter between products (shown in Table A2) and industrial sectors, respectively. Here $\mathbf{d}_1^t$ and $\mathbf{d}_2^t$ represent the long-term tendency and short-term tendency influencing recovery. Parameters s and r are influential factors within ranges [0, 1]. In the article $\mathbf{d}_1^t$ is simulated based on the assumptions that household consumption has a 10% recovery rate for each month, and $\mathbf{d}_2^t$ is calculated as a gap percentage; that is, the total demand minus total production capacity compared against the total demand at each time step.

In regard to imports, it is assumed that commodities from other regions are always available for provision and that the maximum rate of import is equal to the import quantities in the predisaster condition. There is no constraint on types of goods and services imported, except in regard to goods and services that are not suitable for import (e.g., utilities and transportation). The justification for such an assumption is that authorities will prioritize the supply of goods and services to the disaster region if there is an emergency, while supplies from utility sectors (e.g., electricity) are usually provided locally, making it infeasible to have large-scale adjustments to these latter goods and services over the time scale of disaster recovery.

However there are no data or experimental studies on how households or companies react to production shortages by turning to external producers. Here we assume that if the degraded production capacity for industry i cannot satisfy final demand, households will seek imports. When the degraded production capacity for industry i can satisfy both intermediate and final demand due to the reconstruction effort, customers will return to their initial suppliers. However, in the modeling, imports are also constrained by the total "importability capacity," calculated as the product of the import amount in the predisaster time period and the percentage of the transportation sector's recovery by that time period. The import $\mathbf{m}^t$ in sector and final demand categories at time step t is calculated as below:

$$\mathbf{m}^t = \left(\frac{q_{\text{tran}}^{*(t)}}{q_{\text{tran}}^{0}} * \mathbf{m}^0 \right). \tag{17}$$

Here $\frac{q_{\text{tran}}^{*(t)}}{q_{\text{tran}}^{0}} * \mathbf{m}^0$ refers to the importability capacity at time step t, where q_{tran}^{0} and $q_{\text{tran}}^{*(t)}$ are the predisaster and postdisaster (at time step t) total capacities for transport of goods and services by the transport sector obtained from vectors $\mathbf{q}^0$ and $\mathbf{q}^{*(t)}$, respectively. The subscript "tran" refers to aggregate transportation by land, sea, and air.

Decisions to return to the predisaster conditions can be complex and varied. Here, let us suggest two ways of adapting toward a balanced input-output condition (i.e., a balanced Equation (3) reflecting inequality (12)) at each time step for the next round of economic recovery. One approach is simply to adopt a minimal production balance between labor production capacity, industry production capacity, and total final demand. The second is to return to the balance at the end of each time step by an adjustment policy through changes in import and export in three steps:

- First, let us keep sector i's degraded production output—$\mathbf{q}_{\text{deg}}^{t}(i)$—constant in time and cause other sectors j to adjust accordingly in proportion to the balanced economic condition in the predisaster period as shown in the equation:

$$\mathbf{r}^t(j) = \frac{\mathbf{x}^0(j)}{\mathbf{x}^0(i)} \times \mathbf{q}_{\text{deg}}^{t}(i), \tag{18}$$

where $\mathbf{x}^0(j)/\mathbf{x}^0(i)$ is the ratio of production in sector j to sector i in this predisaster time. In this case, $\mathbf{r}$ is a column vector that describes the amount of goods and services required in every sector so that the disrupted economy is balanced by keeping the degraded output of industry i—$\mathbf{q}_{\text{deg}}^{t}(i)$—unchanged. For each sector, a corresponding vector $\mathbf{r}$ is produced.

- Second, compare the amount of imports/exports generated based on the calculation of $\mathbf{r}^t$ with the value of imports/exports at the postdisaster time t. If any sector within $\mathbf{r}^t$ exceeds the limit of import/export for that sector (constrained by transportation sectors), that vector $\mathbf{r}^t$ is ignored; otherwise, it is retained in the model as a possible candidate for $\mathbf{r}^t$ if the following conditions hold:

$$\begin{aligned} &(\mathbf{r}^t(i) - \mathbf{q}_{\text{deg}}^{t}(i)) < \Delta\mathbf{f}_{\text{imp}}^{t}(i), \text{ where} \\ &\quad (\mathbf{r}^t(i) - \mathbf{q}_{\text{deg}}^{t}(i)) > \mathbf{0}; \\ &\text{or } |\mathbf{r}^t(i) - \mathbf{q}_{\text{deg}}^{t}(i)| < \Delta\mathbf{f}_{\text{exp}}^{t}(i) \text{ where} \\ &\quad (\mathbf{r}^t(i) - \mathbf{q}_{\text{deg}}^{t}(i)) < \mathbf{0}, \end{aligned} \tag{19}$$

where $\Delta\mathbf{f}_{\text{imp}}^{t}$ and $\Delta\mathbf{f}_{\text{exp}}^{t}$ are available capacities of current imports and exports, respectively, and $|\mathbf{r}^t(i) - \mathbf{q}_{\text{deg}}^{t}(i)|$ will be met in an IO table either through import or export. The comparison is to check if the import/export values (i.e., $|\mathbf{r}^t(i) - \mathbf{q}_{\text{deg}}^{t}(i)|$) are practical for the currently available capacity to deliver imports/exports. Further, because utility services are assumed to be provided locally, any possible vectors $\mathbf{r}^t$ requiring changes in these sectors are removed.

- Finally, one may opt for one of the possible vectors $\mathbf{r}^t$ left or their average as the return to a balanced production pattern.

However, the procedure has various constraints. For example, imports and exports are limited by the availability of transportation in the postdisaster period; therefore, again there is only a tendency towards economic balance. In the modeling the first approach to returning to balance is adopted, while a sensitivity analysis can be conducted in the future by applying the two different economic balance options and comparing results.

5. DATA

5.1. U.K. Multisectoral Dynamic Model

For this article, the U.K. multisectoral dynamic model—MDM[25]—was used to produce the IO table components consisting of Leontief coefficients,

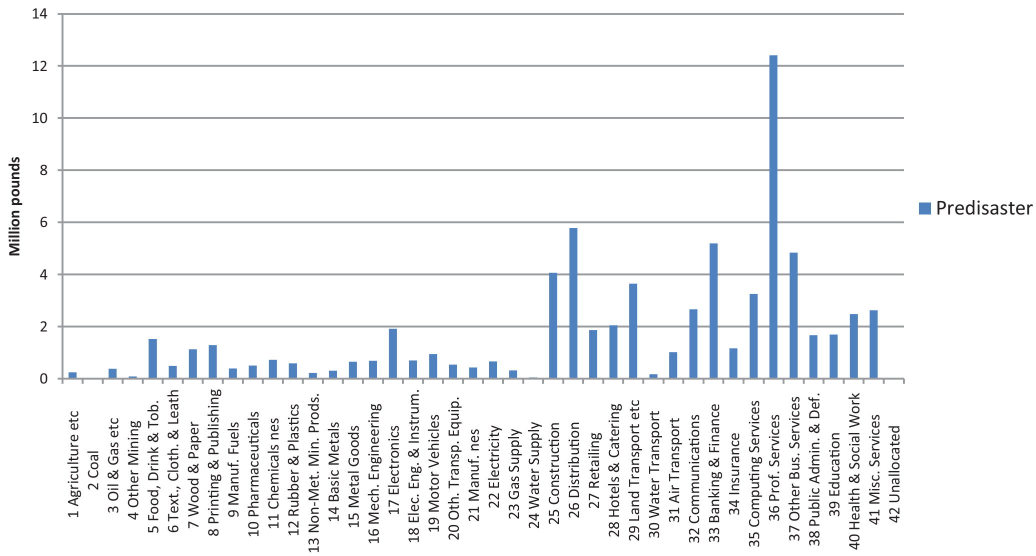

Fig. 1. Monthly industrial outputs in the predisaster period around 2020.

final demand categories, and total outputs specific to London's economy around 2020. Due to the lack of seasonal and monthly production data for London, we assume that London has an identical monthly production pattern as the U.K. national average. Sectoral details of industrial monthly outputs of London's economy around 2020—in terms of a constant price at the 2003 level before the disaster—are shown in Fig. 1.

5.2. Event Accounting Matrix

In Section 3, a flooding event matrix $\mathbf{\Gamma}$ measured by the proportion of production capacity loss for the BDI model was introduced. The degraded production capacity can be calculated from surviving productive capital and stock. Such information is usually estimated by a flooding damage function, which is highly dependent on the particular scale and timing of a disaster event. In this article, a hypothetical flooding event accounting matrix with 42 sectors and labor loss for London's economy around 2020 is introduced in Table I.

Table I contains two sets of information related to direct damage to London's economy: (i) capital loss or damages in sectoral detail, which can be interpreted as the reduction of industrial production capacity as a proportion of predamage capacity, and (ii) labor loss. In this table, labor is taken to be the most vulnerable; that is, 50% of labor in London is unable to provide inputs to economic production immediately after the disaster for this scenario. The service sectors in London are assumed to be the next most affected by the flooding as most of them are currently located close to both sides of the Thames, while the utility sectors are assumed to be resilient because they are located in the remote rural area, relatively far from the river and outside flood plains.

6. RESULTS

The model produces the estimated temporal evolution of total output in London's economy around the year 2020 from the time of the flooding shock ($t = 0$) to the time of full economic recovery. All values displayed in the figures of the article are in million pounds per month, with a constant price at 2003 levels. Fig. 2 shows the monthly inequalities between total production capacity, total demand, and the labor production capacity during the period of economic recovery. The economic imbalance due to the inequalities during the postdisaster period persists, although balance between these factors may occur occasionally during the period of recovery. The labor production capacity recovery is set exogenously and is assumed to recover fully in six months. The total production capacity and total demand recoveries are modeled endogenously. The total production capacity recovery is constrained by capital recovery. The variation shown in the total demand curve is

Table I. Event Matrix Γ^0—The Entries Show the Initial Percentage Loss in Productive Capacity in Each Sector and in Labor Immediately Following the Flooding

1 Agriculture, etc.	30%	12 Rubber & Plastics	20%	23 Gas Supply	10%	34 Insurance	40%
2 Coal	10%	13 Non-Met. Min. Prods.	20%	24 Water Supply	10%	35 Computing Services	40%
3 Oil & Gas etc	10%	14 Basic Metals	20%	25 Construction	30%	36 Prof. Services	40%
4 Other Mining	10%	15 Metal Goods	20%	26 Distribution	40%	37 Other Bus. Services	40%
5 Food, Drink, & Tob.	20%	16 Mech. Engineering	20%	27 Retailing	40%	38 Public Admin. & Def.	40%
6 Text., Cloth., & Leath	20%	17 Electronics	20%	28 Hotels & Catering	40%	39 Education	40%
7 Wood & Paper	20%	18 Elec. Eng., & Instrum.	20%	29 Land Transport, etc.	40%	40 Health & Social Work	40%
8 Printing & Publishing	20%	19 Motor Vehicles	20%	30 Water Transport	40%	41 Misc. Services	40%
9 Manuf. Fuels	20%	20 Oth. Transp. Equip.	20%	31 Air Transport	40%	42 Unallocated	40%
10 Pharmaceuticals	20%	21 Manuf. Nes.	20%	32 Communications	40%	Labor	50%
11 Chemicals nes	20%	22 Electricity	10%	33 Banking & Finance	40%		

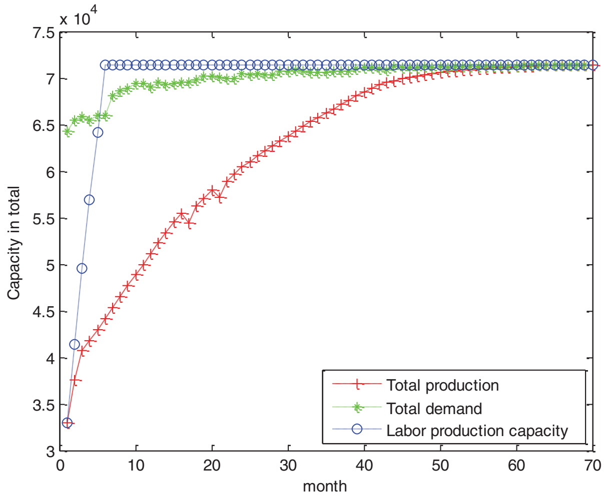

Fig. 2. The total production inequalities between different factors during the recovery.

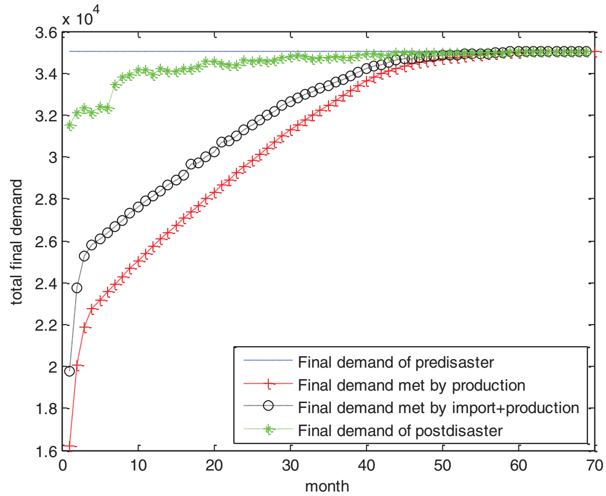

Fig. 3. The total final demand inequalities between different factors.

caused by the simulation of consumer consumption behavior in the postdisaster period (see Equation (16): in the London case study we take the parameter r as a random variable with range $[0, 1]$). From the level of damage as shown in Table I, London's economy recovers in 70 months (about six years). Fig. 3 shows an unequal recovery of final demand. The solid blue line at the top (colors visible in online version) refers to the predisaster total final demand; the green curve with star marker represents the total final demand recovery in the postdisaster period, whose variation is consistent with the total production required by final demand shown in Fig. 2; the red line with plus marker in Fig. 3 shows the final demand met by constrained local production alone; the black line with circle marker in Fig. 3 shows the final demand met by constrained local production plus constrained imports. The difference between the green curve and the black curve at each time step reflects the fact that production does not meet final demand all the way through the postdisaster recovery period (partly due to the rationing scheme including a bottleneck[(7)]), but is narrowed gradually.

In the modeling the proportional rationing scheme involving a bottleneck is adopted; selection is justified in the following sensitivity analysis. Fig. 4 shows a comparison of total production before adopting a bottleneck based on the Hallegatte method[(7)] and after a bottleneck is applied during the recovery period. It shows how much effect the bottleneck may bring. It can be seen from the figure that there is a significant impact at the beginning period—when the rationing scheme and bottleneck balance the intermediate production—while the influence fades as intermediate demand is satisfied by production over time.

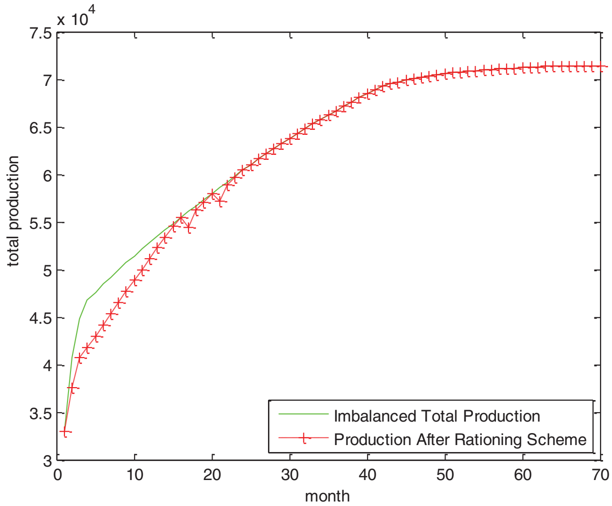

Fig. 4. The distortion of proportional rationing scheme with bottleneck to the total production during the recovery.

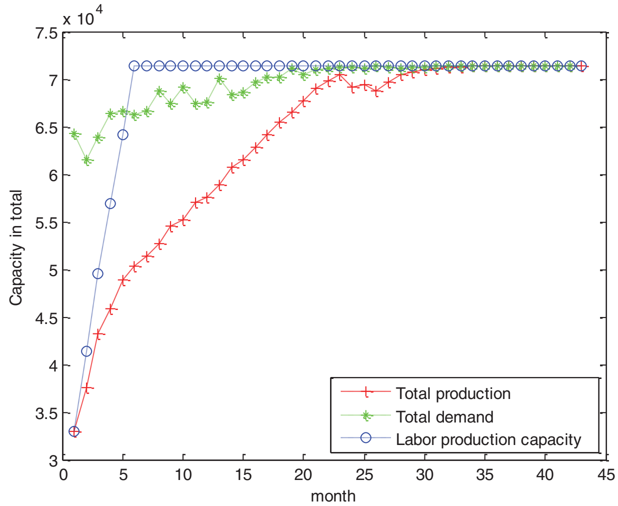

Fig. 5. Unequal recovery given 10% direct loss.

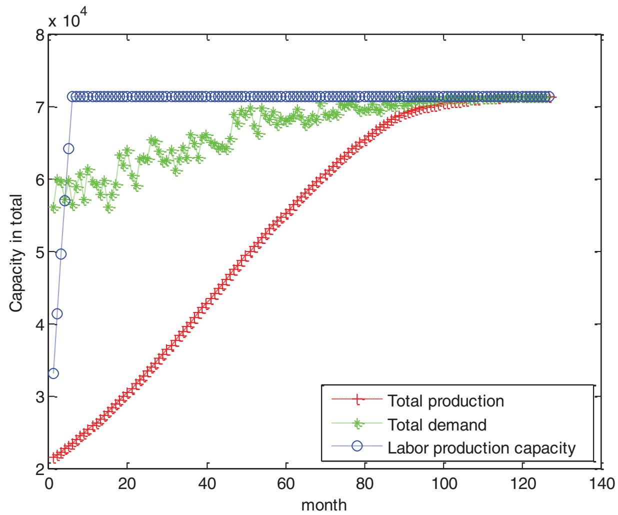

Fig. 6. Unequal recovery given 70% direct loss.

7. SENSITIVITY ANALYSIS

The variations in model inputs, model algorithms, and consumption behavior may have a large effect on the model results. The magnitude of these variations can be evaluated using systematic sensitivity analysis, in which range values, different parameters of equations, algorithms, and assumptions can be applied. In this study, several aspects of modeling variations, such as the scale of disaster, rationing scheme strategies, Leontief matrix, and consumption behaviors, are investigated.

- *Modeling different scales of disaster without changing households' consumption pattern and rationing scheme.* Here a smaller-scale flooding event with 10% direct loss to all industry sectors and a larger-scale flooding event with 70% direct loss to all industry sectors are modeled. Results are shown in Figs 5 and 6.

The two figures show similar recovery paths for total production capacity and total demand, with the labor production capacity recovery path being specified exogenously. The recovery durations for the two modeled cases are 43 months and 126 months, respectively. While in the second case the direct loss is seven times higher than the first, the recovery period is almost trebled.

- *Modeling with different rationing schemes.* In the model, one can employ either the proportional scheme or a priority scheme and adjust the order of priority between household demand and industry reconstruction needs while keeping all other assumptions unchanged. Fig. 7 shows the results of a simulation with the priority as "Intermediate Demand" > "Final Demand for Reconstruction" > "Households Demand" > "Governmental Demand" > "Fixed Capital Formation" > "Exports." Such a priority arrangement is justified by the facts that business-to-business relationships are often deeper and favored over business-to-household relationships;[7] reconstruction and actions to

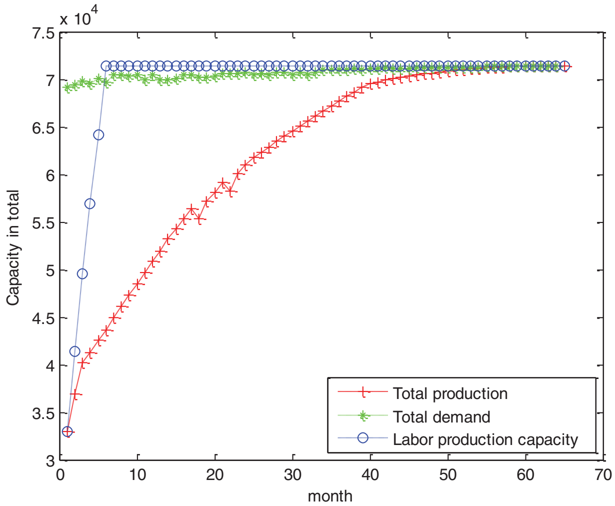

Fig. 7. The recovery based on the damage demand prior scheme.

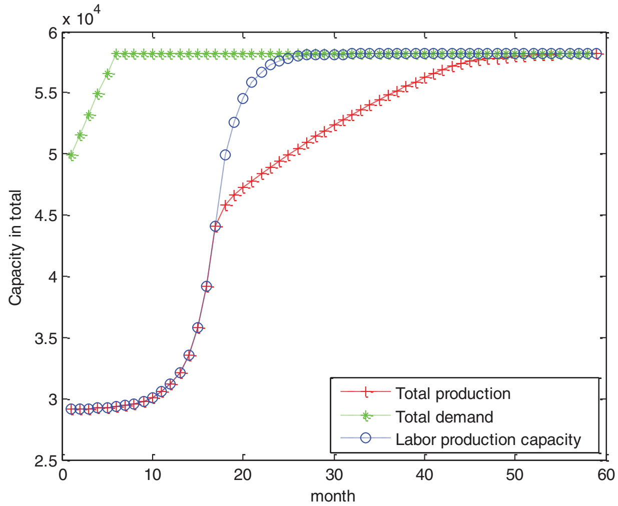

Fig. 9. The total production recovery using alternative assumptions.

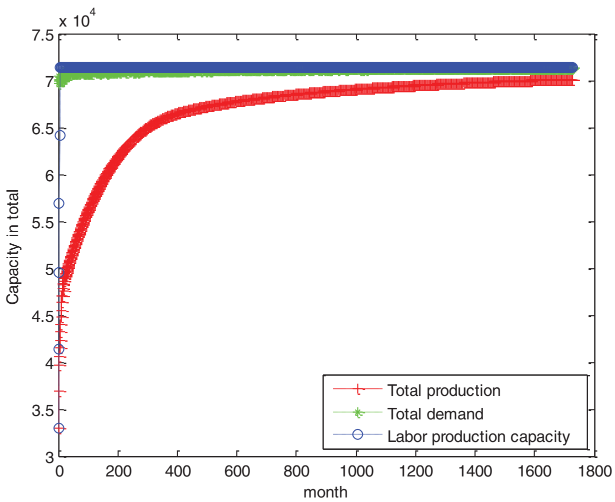

Fig. 8. The recovery based on the final demand prior scheme.

return the economy back to the predisaster condition are considered a priority by the authorities; government consumption always gives priority to household consumption in a postdisaster situation; and exports are ranked lowest because customers from other regions may easily switch to other suppliers and commodities when short of imports from the disaster region. Fig. 8 shows the results of a simulation with an alternative priority scheme to distribute goods to households, government, and exports prior to reconstruction efforts. The result demonstrates that in this latter situation the economy recovers very slowly if at all (>1,727 months). The reason is that economic production capacity and final demand are determined by the restoration of industrial capital. As production in the aftermath of a disaster does not satisfy both the intermediate demand and final consumption, a prior allocation for reconstruction leading to capital recovery is needed. The approximate recovery periods in Fig. 2 (proportional scheme), 7, and 8 are 70, 65, and >1,727 months, respectively. The difference between a proportional scheme as shown in Fig. 2 and a priority scheme with reconstruction having top priority as shown in Fig. 7 is not significant, which demonstrates that a proper proportional scheme applied to the demand for production, reconstruction, household, and other demands is highly recommended to policymakers in a disaster recovery situation. The scheme may give a fairer goods allocation. The lack of recovery shown in Fig. 8 suggests that a reconstruction policy that brings business back to work quickly is essential for the recovery.

- *Modeling with a regional matrix, alternative labor, and household recovery paths.* We next test combinations of three alternative factors: a regional Leontief matrix A, an alternative exogenous labor recovery path, and household consumption recovery path, with other parts of the model left unaltered. Results are shown in Figs. 9 and 10. As discussed previously, the model assumes that London's economy has the

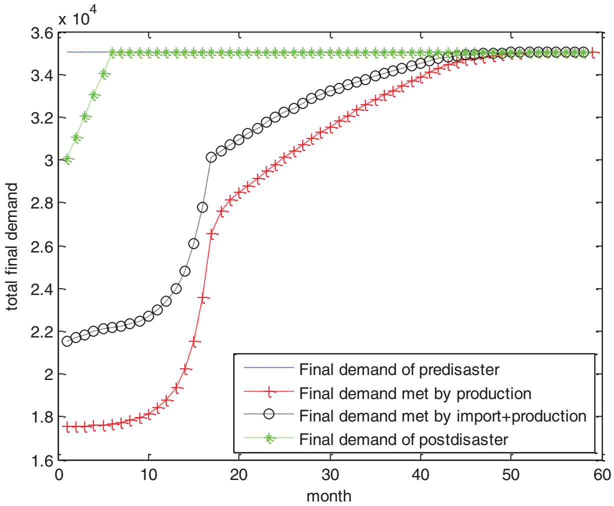

Fig. 10. The final demand recovery using alternative assumptions.

same industrial structure as the national economy and therefore the U.K. matrix A is adopted during the modeling. However, a London technical coefficient matrix may be estimated based on the estimated regional supply percentage; that is, the percentage of the total required outputs from each sector that could be expected to originate within London region, through the equation:[26]

$$p_i = (x_i - e_i) / (x_i - e_i + m_i), \quad (20)$$

where x_i, e_i, and m_i refer to the total regional output, the export, and the import of each sector i of the region, respectively. Then, the regional matrix $\boldsymbol{A}$ is estimated as (in the case of London the number of sectors is 42):

$$A^* = \hat{P}A = \begin{pmatrix} p_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & p_n \end{pmatrix} \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix}. \quad (21)$$

Labor recovery is still assumed to start from the same initial degree of damage, but the path is substituted with an s-shape. It assumes that recovery of the labor rate is slow for the first few months, followed by a sharp increase as people have adapted to the postdisaster situation, and then a leveling-off as the labor force has fully adapted. The altered household consumption recovery is assumed to be fulfilled in six months with the same starting point as shown in Table A2, but the path is set to increase 10% in every following month for degraded consumption rates until the predisaster level is reached.

From the figures mentioned earlier, the recovery process is complete at the 59th month, demonstrating shorter recovery duration in comparison to the 70 months shown in Fig. 2. The large influence of the altering factors is reflected by the shape change in the total production and final demand recovery curves, which also show similar s-shapes. This demonstrates that labor recovery has been playing an essential role in the simulated recovery of London's economy. As labor recovery relies heavily on transportation and health care provision, policies emphasizing these sectors should be a top priority for authorities in a postdisaster period.

8. CONCLUSIONS

This article proposes a framework for modeling an imbalanced economic recovery process in a postdisaster period using IO analysis. Labor, capital, and final demand are among the major constraints that influence and distort an economic balance and recovery; that is, the imbalance between them is a driving factor along the pathway of recovery for an affected economy. A series of dynamic inequalities is developed as a theoretical basis for the modeling, based on which economic conditions following a hypothetical disaster occurring in London around 2020 are taken as a scenario to assess the influence of future shocks on a regional economy. The model simulates reconstruction demand, labor, and capital recovery, consumption behavior and imports constrained by rationing schemes, connected through the IO table and driven by the inequalities between them, influenced by short-term economic rebalance and long-term recovery tendencies.

Along with the framework, a macroeconometric model—MDM—is used to project the baseline conditions at the time of the disaster. The modeling results show that London's economy recovers with the reconstruction complete in 70 months (about six years) by applying a proportional rationing scheme under the assumption of 50% labor loss (with full recovery in six months), 40% initial loss to service sectors, and 10–30% initial loss to other sectors. The inequalities and results also suggest that the imbalance during a postdisaster period will persist, although balance may occur temporarily during the recovery period.

There are large variations in results caused by selection of data, behavioral assumptions, and model methodologies. The article studies several aspects of modeling variations including the scale of disaster, rationing scheme strategies, the Leontief matrix employed, and household consumption behaviors. The modeling on different scales of disaster provides a comparison of recovery trajectories and durations; the modeling on different rationing schemes suggests a proportional scheme may be a proper strategy used for rapid postdisaster economic recovery with a fair balance between final demand actors; the modeling on an estimated regional matrix shows that the influence on recovery time is minimal under current assumptions and data applied; the modeling with different labor recovery paths demonstrates that prior policies in transportation recovery and health care are essential in postdisaster economic recoveries.

One further extension of the model is in the area of economic agents and primary factors dynamics simulation. For example, in the postdisaster period labor productivity is likely to change. If people take longer time traveling to work, they may choose to nonetheless complete their required work assignments or tasks; this would reduce the influence of transportation loss on economic production. Moreover, the framework needs to be further justified by applying real disaster scenarios data; a comprehensive sensitivity analysis on key parameters of the dynamic inequalities might then be conducted. In addition, endogenizing the flooding damage function to determine surviving productive capital and stock is recommended when feasible.

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APPENDIX

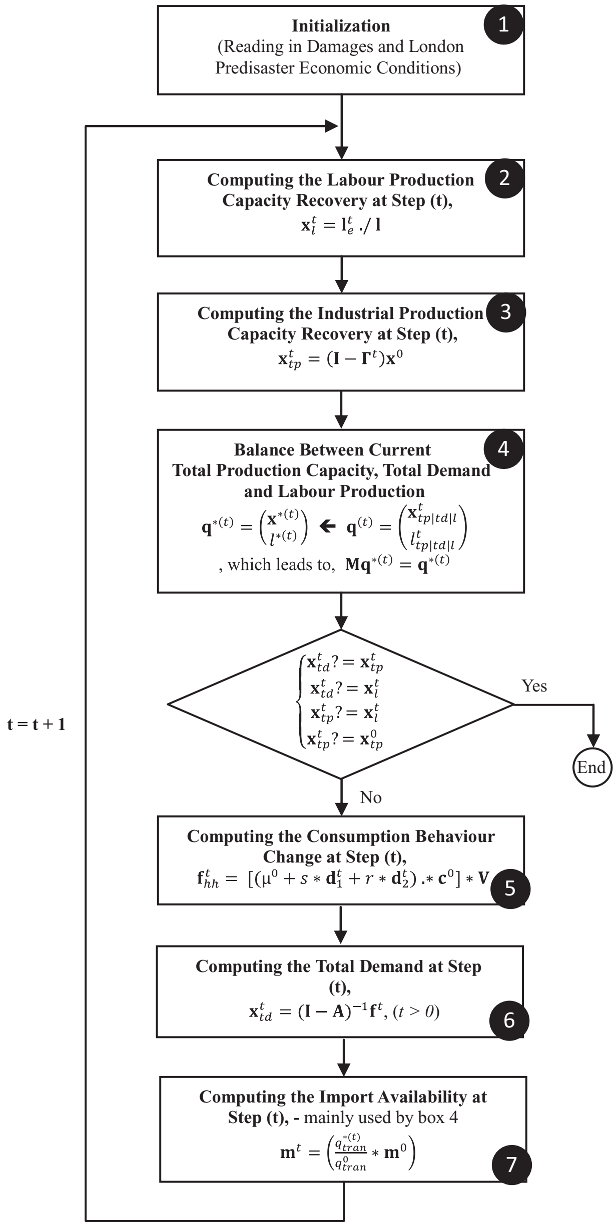

Fig. A1. Modeling imbalanced economic recovery following a London flooding event around 2020 using input-output analysis. The diagram, which has been described in Section 4.1, is the modeling process for the London case study based on the general framework developed in Section 3 (mainly Equations (1)–(12)). In the London case the framework is further enriched based on a defined scenario and further assumptions by simulating labor force recovery (box 2 of Fig. A1), rationing scheme (box 4), consumption behavior change (box 5), and imports dynamics (box 7), etc. Here the solid lines form a recovery circle within a time step (i.e., a month).

Table A1. The Assumption of Labor Recovery of All Sectors in London Case, $\mathbf{l}_e^t$

	Sectors
Month 1	
Loss recovery in percentage term	0.5
Travel delay: number of hours per day (o_1)	3
% of labor affected of delaying (p_1)	10%
Month 2	
Loss recovery in percentage term	0.6
Travel delay: number of hours per day (o_2)	2
% of labor affected of delaying (p_2)	8%
Month 3	
Loss recovery in percentage term	0.7
Travel delay: number of hours per day (o_3)	1
% of labor affected of delaying (p_3)	5%
Month 4	
Loss recovery in percentage term	0.8
Travel delay: number of hours per day (o_4)	1
% of labor affected of delaying (p_4)	2%
Month 5	
Loss recovery in percentage term	0.9
Travel delay: number of hours per day (o_5)	0.5
% of labor affected of delaying (p_5)	1%
Month 6	
Loss recovery in percentage term	1
Travel delay: number of hours per day (o_6)	0
% of labor affected of delaying (p_6)	0%

Note: Here two scenarios are given: the labor capacity recovery is either based on the loss recovery in percentage terms directly or, more specifically, calculated according to "% of labor affected of delaying" × "Travel delay: number of hours per day" × 22/(8 × 22). In the London flooding scenario modeling, the first one is used.

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Table A2. Reduced Household Consumption Demand Immediately After the Disaster in Fraction of Predisaster Levels, $\boldsymbol{\mu}^0$

1 Food	1	14 Gas	0.5	27 Petrol & oil	0.5	40 Educational services	0.5
2 Nonalcoholic drinks	1	15 Coal & coke	0.5	28 Running costs(m/v)	0.5	41 Catering services	0.5
3 Beer	0.5	16 Other fuels	0.5	29 Rail travel	0.5	42 Accommodation servs	0.5
4 Spirits	0.5	17 Furniture & carpets	0.5	30 Buses & coaches	0.5	43 Personal care	0.5
5 Wine, cider & perry	0.5	18 Household textiles	0.5	31 Air travel	0.5	44 Personal effects nec	0.5
6 Tobacco	0.5	19 Household appliances	0.5	32 Other travel	0.5	45 Social protection	0.5
7 Clothing	0.5	20 Tableware & hh utens	0.5	33 Communications	0.5	46 Insurance	0.5
8 Footwear	0.5	21 Tools & equipment	0.5	34 AV, photo, &info eq	0.5	47 Financial servs nec	0.5
9 Actual rents (hsg)	0.5	22 Gds & servs hh maint	0.5	35 Other durables	0.5	48 Other services nec	0.5
10 Imputed rents (hsg)	0.5	23 Medical products	1	36 Other recreational eq	0.5	49 Expenditure abroad	0.5
11 Maintenance of hsg	0.5	24 Out-patient services	1	37 Rec & cultural servs	0.5	50 Foreign tourists exp	0.5
12 Water & dwel. serv	0.5	25 Hospital services	1	38Newspapers & books	0.5	51 NPISH final exp	0.5
13 Electricity	0.5	26 Purchase of vehicles	0.5	39 Package holidays	0.5	52 Unallocated	0.5

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