Towards Construction of an Earthquake Disaster Model that Incorporates Supply Chains

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Economic Effects of Great East Japan Earthquake

This study explores the dimensions of an appropriate model for estimating damage from earthquakes and the issues to be considered in this respect, and is grounded in the experience of the Great East Japan Earthquake. They will be the subject of study in the "Workshop Concerning the Impact of Mega-Disasters on the Mid-to Long-Term Japanese Macro-economy" (Economic and Social Research Institute (ESRI), Cabinet Office).

It should first be recognized that the economic damage from an earthquake is multi-layered. Damage from the Great East Japan Earthquake has totaled more than 16.9 trillion yen, according to a Cabinet Office estimate. This covers "direct damage" to infrastructure, production facilities, buildings and the like. A Tokyo metropolitan earthquake at its most devastating could cause 66 trillion yen worth of such direct damage. However, damage is not limited to the direct kind. Damage to infrastructure and the like – "indirect damage" – causes a decrease in economic activity after an earthquake, and consequent loss of economic value. Joji Tokui, Kazuyasu Kawasaki, Kyoji Fukao, Kazuma Edamura, and Naohiro Noguchi (*The Economic Impact of the Great East Japan Earthquake: Comparison with Other Disasters, Supply Chain Disruptions, and Electric Power Supply Constraints,* PDP RIETI Policy Discussion Paper Series 12-P-004, 2012) categorize damage due to destruction and other damage to "stock" as direct damage and "flow damage" as indirect damage. The economic term for this indirect damage is "opportunity costs" – or "forgone earnings" – in the sense of the value lost that would have accrued had the earthquake not occurred.

Important features of the indirect damage due to this earthquake were (i) shredded supply chains and (ii) the electricity shortage resulting from the Fukushima Dai-ichi nuclear accident. The growing complexity of the production process typical of the automobile industry was the backdrop to the shredded supply chains. Another important factor was the shift by Japanese manufacturers to special-order material and components in their drive to become unique "only-source companies" in the face of increasingly harsh global competition driven by the rise of emerging economies and other factors. This indirect damage did not stop at the borders of the disaster areas. Production also stopped outside the disaster areas in places dependent on materials and components supplied from them *(Table 1)*.

Supply chains, to be sure, quickly began to recover. By June 2011, 80% of the production bases damaged in the Great East Japan Earthquake had recovered to or surpassed pre-earthquake production levels, according to the "Emergency Survey of the Current State of Industries" by the Ministry of Economy, Trade and Industry (METI), while 97% of manufacturers had already begun sourcing from alternative sources, and the proportion of firms that were unable to find alternative sources had decreased from 12% at the time of an April survey to 0% in basic materials industries and from 48% to 18% in processing industries.

How about the electricity shortage? Tokyo Electric Power Co. (TEPCO) managed through the first post-earthquake weeks with scheduled (rolling) blackouts, in which it stopped supplying electricity for a specific period district by district. The economic loss would be massive if this electricity rationing reminiscent of wartime were continued. One provisional estimate put the GDP loss at 5.4 trillion yen, or 1.04% of annual GDP, if the three-hour blackouts in the scheduled areas in the nine prefectures supplied by TEPCO continued until the end of April (*Reuters,* March 23, 2011). The impact was not limited to East Japan. If nuclear reactors had remained offline through the summer, there were concerns that the Kansai region would suffer a loss of up to 3.5% of its GDP in July-September 2012 (*The Kansai Economy after the Great East Japan Earthquake,* Japan Research Institute, July 2011).

TABLE 1

Disaster-hit companies' immediate reaction

Nissan Motor Co.	Partial suspension of operations at the Oppama and Yokohama plants in Kanagawa Prefecture and suspension of operations at the Tochigi plant in Tochigi Prefecture extended to March 20, as prospects for recovery at the Iwaki plant in Fukushima Prefecture remained unclear.
Suzuki Mortor Corp.	Suspension of domestic operations originally scheduled through March 16 extended to March 21.
Daihatsu Motor Co.	Suspension of operations at four vehicle assembly plants and one engine plant extended to March 20.
Seiko Epson Corp.	About 360 employees evacuated from a subsidiary electronic parts producer located within 30 kilometers of the nuclear power plant. One of Seiko Epson's main plants producing electronic parts essential for mobile phones and other such products suspended; likelihood of impact on mobile phone and other manufacturers if production suspension continues.

Source: Compiled by author with reference from Mainichi Shimbun, March 16, 2011

TABLE 2

Multi-layered economic damage from an earthquake

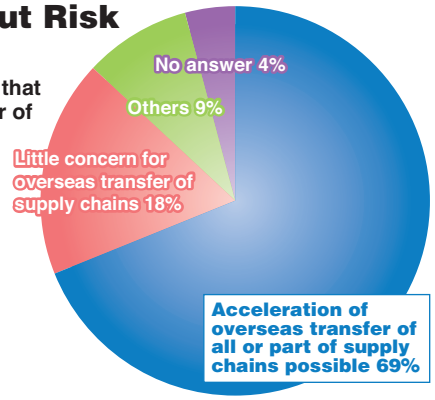
Primary damage	Direct earthquake damage to infrastructure, buildings, factories, etc.
Secondary damage	Ripple effect beyond disaster areas — shredded supply chains — electricity shortages
Tertiary damage	Structural damage to disaster areas & Japanese economy — outflow of firms and investment — loss of competitiveness

Source: Compiled by author

CHART 1

Hollowing-out Risk

[Question]
Is there a possibility that the overseas transfer of your supply chains will be accelerated after the Great East Japan Earthquake?



Source: METI

Multi-layered Damage from Earthquakes

Motohiro Sato and Kazumasa Oguro identify three layers *(Table 2)* in the economic effects of the 3.11 earthquake disaster (*Analysis of the Impact of a Direct Earthquake Hit on the National Capital on the Macro-Economy,* Economic Analysis, No.184, 2011). Primary damage means direct damage, while secondary damage covers shredded supply chains and the like. As previously mentioned, the distinguishing characteristic of this secondary damage is that it extends beyond the disaster areas. Moreover, the earthquake disaster itself may be a "temporary shock" but it could have a "structural impact" on the growth and development of the economy of the disaster areas and even the Japanese economy itself if recovery is delayed. Such is the tertiary damage. According to METI's "Emergency Questionnaire Survey of the Recovery and Reconstruction of Supply Chains and the State of Industrial Hollowing Out after the Great East Japan Earthquake" conducted in April 2011, in response to the question "Is there a possibility that the overseas transfer of your supply chains will be accelerated after the Great East Japan Earthquake?" 69% answered that "There is a possibility that the overseas transfer of all or part of the supply chains will be accelerated." *(Chart 1)*.

The extent of this tertiary damage should depend on the speed and nature of the reconstruction after the earthquake. Delays in the reconstruction process including the disposal of debris could inflict structural damage. "Reputational damage" also increases tertiary damage. Indeed, the consequences of the nuclear accident were not limited to the disaster area and inflicted serious damage on the brand images of Japanese products. Some 47% of Americans, 27% of Britons, and 72% of Chinese cited radioactive contamination as a cause for concern about Japanese products, according to a Cabinet Office document dated June 23, 2011. If the electricity shortage had continued on top of this, it could have accelerated the outflow of businesses and capital.

The Port of Kobe is an example of how an earthquake shock can lead to "structurally built-in" damage. The port used to process some of the highest volumes of cargo in the world before the Great Hanshin-Awaji Earthquake of Jan. 17, 1995. However, it lost its role to Busan in South Korea as the international trading network was rearranged while it had temporarily ceased to function properly. The Port of Kobe had ranked sixth worldwide in container tonnage, but dropped as low as 44th in 2007 as the number of containers handled there fell sharply.

TABLE 3

Issues concerning earthquake disaster model

Issue	Response
Estimate damage according to economic conditions	Estimates corresponding to economic conditions (boom or recession)
Effect of economic damage over time	Utilization of macroeconomic models
Supply chains	Utilization of inter-industry (input-output) relationship analysis
Fiscal & financial constraints	Modeling economic & financial systems

Source: Compiled by author

Provisional Estimate of Economic Effects of Earthquake Disasters

The 2011 Annual Report on the Japanese Economy and Public Finance estimates that the Great East Japan Earthquake pushed down potential Japanese GDP about 1% (approximately 6 trillion yen on an annual basis). The main reason for this was the temporary constraint on supplies due to shredded supply chains and the electricity shortage. As overall demand also fell due to negative consumer sentiment looking forward, it is hoped that the economy will maintain its recovery path, helped along by recovering supply chains and reconstruction demand. In October 2011, the OECD revised its FY 2011 real GDP growth estimate for Japan from its May estimate of minus 0.9% to minus 0.5%, and forecast 2.1% growth in FY 2012 as the result of reconstruction demand and other factors. Nevertheless, Japan's post-earthquake economy currently embodies risk around tertiary damage, including the reverberations of the nuclear accident.

In any case, the Great East Japan Earthquake revealed the various issues regarding the construction of a model for estimating damage. *Table 3* gives a list of these issues. First, previous damage estimates tended to be biased towards direct (primary) damage. The maximum 66 trillion yen for direct damage from a Tokyo metropolitan earthquake was calculated by estimating the ratio of damage to buildings and other stock based on the "external force" derived from the magnitude of the quake, then multiplying this ratio by the value of the stock located in the respective areas. The direct damage corresponds to the recovery costs in the sense of restoring the stock to its original condition.

In the case of production facilities, however, the scale of the damage would depend on the operating ratio at the time of the earthquake. Very little is lost by way of earnings in the case of a facility that has been idled. In the case of roads and other social infrastructure, some are utilized sparingly, to the point of being called "waste". From an economic perspective, the important thing should be the economic value (on a present value basis) of the damaged infrastructure. Damage estimates are often categorized by the time of day and wind speed. However, categorization by the state of the economy (e.g. boom or recession) would also make sense. As mentioned above, the 16.9 trillion-yen damage estimate for the Great East Japan Earthquake does not reflect "forgone earnings" either. To be blunt, previous estimates have been made from a civil engineering, not an economic, point of view.

Earthquake Reconstruction Process

Previous estimates for indirect damage were generally limited to the impact in the year of the earthquake and did not necessarily include the recovery and reconstruction process. In addition, they consisted solely of the impact on the supply side and did not include the effect on the demand side, such as consumption and investment. Sato and Oguro used a simple macroeconomic model to conduct a quantitative evaluation of the mid- and long-term impact on the economy of a Tokyo metropolitan earthquake. Their study is distinguished by its inclusion of the recovery and reconstruction process and its effect on domestic demand (reconstruction demand) based on the experience of the Great Hanshin-Awaji Earthquake. Specifically, it estimates (based on consumption propensity and other factors) macroeconomic structural variables from past data and uses the Monte Carlo method to simulate post-earthquake trends in the economic growth rate, interest rates, price levels, foreign exchange rates, unemployment rates and other macro-variables.

The study also gives a preliminary calculation for the Great East Japan Earthquake using the same method. The results show that the short-term economic growth rate is higher than if there had been no earthquake. This is because the positive effect of the additional demand from reconstruction activities on the real growth rate is greater than the negative effect of the damage to stock, loss of manpower, and temporary drop in consumption demand on the growth rate. The real post-earthquake growth rate tends to drop over the mid-term. But this decrease remains within the 0.7 percentage point range.

However, the study (i) introduces investment and consumption functions and other functions on an *ad hoc* basis, not on the basis of ("forward-looking" in the sense of taking the future into account) optimization by households and firms; (ii) does not reflect secondary damage in the form of the impact of supply chain shutdowns; and (iii) fails to consider tertiary damage in the form of damage to the economic structure, deeming the earthquake to be a temporary shock. In other words, it assumes there would be no difference in the economic potential of the Japanese economy before and after the earthquake.

Supply-Chain Issue

The third issue in earthquake disaster models is the matter of supply chains. The Great East Japan Earthquake exposed the fragility of the Japanese supply chain. It does not have a "pyramid" structure, in which the subcontracting firms are widely spread out. Instead, it is more of a "diamond" structure, in which secondary and tertiary subcontracting firms are shared. (In other words, the firms are connected not only vertically but also horizontally.) One way of modeling this supply-chain relationship is through inter-industry relationship (input-output) analysis. The ripple effect of the earthquake damage in one region or industry on other areas can be demonstrated by including transactions between industries and regions. In their policy discussion paper, Tokui, Kawasaki, Fukao, Edamura, and Noguchi provide an analysis of earthquake damage estimates using inter-region input-output tables. Specifically, the study estimates the value of damage for each industrial sector and distinguishes between the primary ripple effect, which takes into consideration the short-term impossibility of substitution, and the secondary ripple effect, which recognizes a certain level of substitution. The results are: 0.11% of GDP for direct damage alone, 0.26% including the primary ripple effect, and 1.35% including all effects. The study reconfirms the incidence of indirect ripple effects that are far greater than the direct damage.

Implications of Fiscal & Financial Crises

An earthquake crisis could lead to fiscal and financial crises. Modeling this is the third issue. Concerning the effect of the Great East Japan Earthquake, with no tax increase for reconstruction, the FY 2011 primary fiscal balance would worsen by 1% of GDP after the earthquake and the 2020 public debt outstanding would be higher by 7-10% of GDP, according to provisional estimates by Sato and Oguro. If we take the probability of the public debt rising to 90% or more of financial assets held by individuals – in other words, it becomes increasingly difficult for the domestic market to absorb public bonds – and call it "fiscal breakdown probability", this figure for 2020 would effectively double from the pre-earthquake 12% to 25%. Note that the estimates are based on the experience of the Great Hanshin-Awaji Earthquake.

How post-earthquake reconstruction will proceed depends on reconstruction projects, tax increases and other "fiscal response" measures. Fiscal conditions could hamper this response and "fetter" post-earthquake reconstruction. Indeed, given the significant deterioration of the fiscal situation, the market's confidence in Japanese government bonds may be harmed by an increase in the fiscal deficit to finance post-earthquake reconstruction (even though it would only be financing a temporary increase in expenditures). There would be a need for caution in tax cuts and reconstruction budgets entailing increased expenditures. The controversy over how to secure the fiscal resources for reconstruction after the Great East Japan Earthquake occurred precisely because the fiscal constraints had become tighter.

Fiscal constraints are not the only worry; financial constraints can also hamper post-earthquake reconstruction. A firm that has suffered damage and intends to make new capital investments to rebuild its business and restore production may find that its regular bank has also suffered damage and is less capable of providing loans, or that damage to fixed assets has lowered their collateral value, making it difficult to secure loans. A firm that already has a heavy debt load may fall into a "double debt" trap. If bankruptcies increase as a consequence of the earthquake, financial institutions will have bad loans on their hands, perhaps making them more cautious about lending even to firms that did not suffer damage. Here, secondary damage spreads through the financial chain (similar in fashion to the supply chain). Moreover, if these things lead to a delay in post-earthquake reconstruction, the situation could end up causing tertiary damage too. To the best of my knowledge, no earthquake disaster model has been constructed that incorporates such financial constraints.

Towards Construction of an Earthquake Disaster Model

Theoretically, the ripple effect of a large earthquake should begin with a fall in production capacity on the supply side (due to destroyed capital

assets and diminished labor supply from human casualties) and a rise in overall demand commensurate with reconstruction demand. The decrease in supply and the increase in demand together will cause a rise in price levels. Demand for reconstruction funds will push up interest rates. In the short-term, the generation of macroeconomic demand may have a positive effect on economic growth. Especially if the disaster occurs during a recession, reconstruction demand will have the effect of raising the floor for the economy. In the mid to long term, supply factors should grow in importance. On the external front, rising domestic demand will increase imports while the drop in production capacity will decrease exports. So, generally speaking, a disaster will cause the trade balance to deteriorate. On the other hand, rising interest rates may lead to an inflow of money from overseas, keeping the yen from losing as much value as it otherwise would.

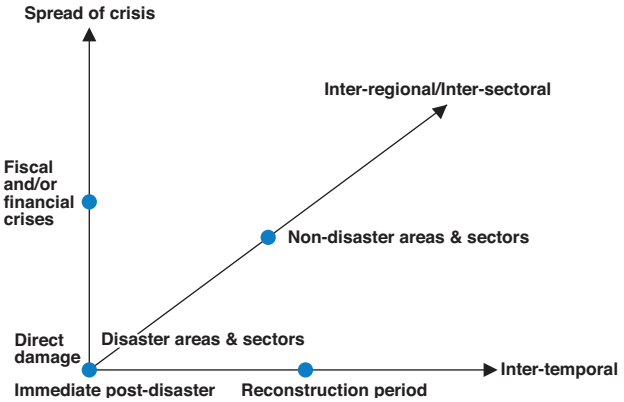
Of course, it is impossible to construct a universal model capable of producing estimates of the economic effects of all kinds of earthquakes, including a Tokyo metropolitan earthquake and a Nankai Trough earthquake. However, it will be useful to provide a common framework for comparison purposes, among other things. Sato and Oguro utilize an economic model for a Tokyo metropolitan earthquake to estimate the damage from the Great East Japan Earthquake. However, as previously mentioned, they verify the ripple effect of the earthquake by solving simultaneous equations consisting of consumption functions, investment functions and other major economic equations. The structure is Keynesian and lacks a "microeconomic basis" since it does not incorporate optimization behavior by households and other economic agents. In order to produce rigorous damage estimates, the development of a general equilibrium model that incorporates optimization corresponding to future expectations of forward-looking economic agents and the adjustment of supply and demand through the market is necessary. Benjamin Keen and Michael Pakko have discussed optimal monetary policies that should have been implemented to cope with the damage and recovery from Hurricane Katrina using a dynamic stochastic general equilibrium (DSGE) model (*Monetary Policy and Natural Disasters in a DSGE Model: How Should the Fed Have Responded to Hurricane Katrina?* Federal Reserve Bank of St. Louis, Working Paper, 2007-025). The dynamic nature of the DSGE model enables it to produce estimates over the course of post-earthquake reconstruction. Its "stochastic" nature incorporates uncertainties in the economy including disaster risks. However, the DSGE model takes as its subject the economic cycle (under normal economic conditions), while long-term trends are assumed to be constant. In other words, a disaster is a temporary shock, and things will revert to normal in the long run. Damage to the economic structure as the result of delays in reconstruction is not considered. In order to analyze this, an expansion to an economic growth model is necessary.

Three Dimensions of Earthquake Models

The foregoing shows that earthquake disaster models consist of three dimensions *(Chart 2)* summarizing the above discussion. The first dimension is the shredding of supply chains and other spatial (inter-regional and/or inter-sectoral) ripple effects. Inter-industry (input-output) relationship analysis is being used to model this, but the existence of only-source companies and the non-substitutability of special-order products and parts have not been sufficiently incorporated. The second is the (inter-temporal) effect of the earthquake disaster over time. Its scope is determined by the scope of post-earthquake reconstruction through production recovery at the disaster-stricken firms and reconstruction projects and the like, including fiscal outlays. The third dimension is the fiscal and financial crises risk generated by earthquake disasters.

CHART 2

Three dimensions of earthquake disaster models



Source: Compiled by author

Policy Implications

Finally, I would like to speak to the policy implications of earthquake disaster models. First, it is wrong to accept the results of damage estimates as inevitable. Damage can be limited through disaster prevention activities and other proactive measures. In fact, there have been positive analyses demonstrating that economic growth accelerates after disasters, such as one by Mark Skidmore and Hideki Toya (*Do Natural Disasters Promote Long-Run Growth?* Economic Inquiry, Vol. 40, Issue 4, 2002). Secondly, it is also necessary to take note of the welfare effect of earthquake disaster reconstruction, since this differs between the nation as a whole, disaster areas, and disaster-stricken firms. To the disaster-stricken firms, reconstruction means the recovery of production and profits, so relocation of production bases can be an option. However, an outflow of firms will be detrimental to the economic recovery of the disaster areas. From the perspective of these areas, it may be enough to return production and employment to pre-earthquake levels. However, reconstruction that maintains firms and industries that lacked competitiveness before the earthquake (so-called "zombie" firms) requires state assistance, and the cost of such fiscal assistance will fall on the shoulders of the Japanese people. This is contrary to the national interest as a whole.

Estimating the economic effects of an unforeseen "low-incidence, high-damage" disaster such as the Great East Japan Earthquake poses many difficulties. However, notwithstanding the limitations, earthquake models could provide guidelines for counter-disaster measures based on evidence and logic instead of extreme pessimism or expectations based on little but hope. JS

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