Earthquake sequential pattern's effect on total economic loss: a simulation study using multi-regional recursive dynamic Computable General Equilibrium models.

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Abstract

The 2011 Tōhoku earthquake and tsunami had several quake focal areas, which moved simultaneously, producing an earthquake of magnitude 9.0. After the earthquake, the Japanese government re-estimated the risk of a large earthquake along the Nankai Trough, where the Philippine Sea plate subducts beneath southwest Japan. The government concluded that there is a 70% chance of a large Nankai Trough earthquake occurrence in the next 30 years. The purpose of this study is to estimate the economic loss caused by the next Nankai Trough earthquake considering a possible scenario in which a large earthquake is triggered by a small earthquake following a time lag of several years. Specifically, this study focuses on the effect of investors' anxiety over possible large earthquakes on their investment behavior. We assume that investors' behavior depends on the sequential pattern of the earthquake. If investors expect a pattern—that is, a small earthquake along the Nankai Trough will trigger a large earthquake several years later—they might decrease their investment in potentially affected areas. Instead of a decrease in investments, consumption would increase in potentially affected areas by the same amount. The simulation result indicates that the economic loss arises and amplifies before the large earthquakes occur due to investor anxiety over future earthquakes.

1. Introduction

The 2011 Tōhoku earthquake and tsunami had several quake focal areas, which moved simultaneously, producing an earthquake of magnitude 9.0. After the earthquake, the Japanese government re-estimated the risk of a large earthquake along the Nankai Trough, where the Philippine Sea plate subducts beneath southwest Japan. The government concluded that there is a 70% chance of a large Nankai Trough earthquake occurrence in the next 30 years. Studies have shown that inter-plate earthquakes have recurred along the Nankai Trough. These studies also indicate that the historical sequential pattern of major earthquakes along the trough is varied. There are six rupture segments distributed along the Nankai Trough according to researchers. The latest simulation research on an earthquake cycle along the Nankai Trough provides a possible scenario in which a small earthquake occurs in the southern area of the Nankai Trough. Four years after the small earthquake, a large earthquake (triggered by the small earthquake) occurs in the southeastern area of the Nankai Trough. One year after the first large earthquake, a second large earthquake occurs in the eastern area of the

Nankai Trough, which is triggered by the former earthquakes (Hyodo, Hori and Kaneda, 2016).

Earthquakes of magnitude 8.1 have been registered in 1944 and 1946. It is now accepted that the latter earthquake was triggered by the former one. Further back, in 1854, two earthquakes of magnitude 8.4 occurred with the time lag of a day, and, in 1707, an earthquake of magnitude 8.6, characterized by several quake focal areas moving simultaneously, was registered. Therefore, earthquake sequential patterns should be taken into account when studying the social and economic impact of a Nankai Trough earthquake.

The purpose of this study is to estimate the economic loss caused by the next Nankai Trough earthquake considering the aforementioned sequential pattern with a time lag of several years. Specifically, this study focuses on the effect of investors' expectations or anxiety concerning potential large earthquakes on their investment behavior. We assume that investors' behavior depends on the sequential pattern of the earthquake. If investors expect a quake pattern—that is, a small earthquake along the Nankai Trough will trigger a large earthquake several years later—they might decrease their investment in potentially affected areas. Instead of a decrease in investments, consumption would increase in potentially affected areas by the same amount, due to investor anxiety. This study examines whether or not investor anxiety following a small earthquake increases the total economic loss involved in a large earthquake. In other words, we examine the effect of the time lag of the sequential earthquake on the total economic loss caused by a large Nankai Trough earthquake. The total economic loss is the economic loss caused directly by the earthquake in addition to the economic loss stemming from the change in investment behavior prior to the large earthquake.

2. The model

In order to begin the examination, we will carefully consider inter- and intra-industry linkages across regions. As the 2011 Tōhoku earthquake and tsunami exemplified, these linkages lead to economic losses spreading to regions that were initially unaffected, which amplifies the total economic loss. Hence, we develop a multi-regional recursive dynamic Computable General Equilibrium (CGE) model with monthly time steps. We calibrate the parameters of the CGE model using an inter-regional Input–Output (I-O) table for the Japanese economy in 2005. All of Japan's 47 prefectures make up the regional classifications in the CGE model. There are 20 commodity classifications in the CGE model, as follows: agriculture; forestry and fishery; food manufacturing; textiles and apparel; pulp and paper products; print and publishing; chemical products; plastic products; non-mineral products; metal products; general machinery; electric machinery; electronic parts; motor vehicle; shipbuilding; other transport equipment; precision machine; construction; electricity, gas and water; and services. The Armington assumption, in which imported goods are imperfect substitutes for domestic goods, is employed to model inter-regional industrial linkages, as well as the inter-regional linkage between industry and final demand sectors. From the perspective of economic dynamics, the model assumes that a constant proportion of household income is saved and invested in capital stock in the next period, that is, our CGE model is not a forward looking dynamic CGE model. The model makes the "putty-clay" assumption regarding capital accumulation. According to this assumption, extant capital stock is production sector- and region-specific; hence, extant capital cannot move across sectors and regions. The putty-clay assumption denies the instantaneous movement of capital stock across production sectors and regions; hence, it is realistic for a simulation using monthly frequency. On the other hand, newly invested capital is mobile across production sectors. The distribution of the newly invested capital is modeled using a constant elasticity of transformation (CET) function. The new investment crosses industrial boundaries within a prefecture so as to maximize returns from the investment.

In the model, the investor anxiety is modeled by change in the saving rate of a representative household in potentially affected areas. When the small earthquake that is a precursor to the large earthquakes occurs, the saving rate of the representative household in potentially affected areas decreases, leading to a decrease in investment toward production sectors in the potentially affected areas. Instead of the decrease in investment, the representative household increases final consumption by the same amount.

3. Simulation setting

We examined two scenarios with respect to the earthquake sequential pattern. Firstly, only one large earthquake occurs along the Nankai Trough in the second period considered in simulation. In this earthquake sequential pattern, several quake focal areas move simultaneously along a wide area of the Nankai Trough. The earthquake is not triggered by another preceding one. This scenario corresponds to a "no time lag" scenario. In the no time scenario, investors are not able to decrease their investment prior to the earthquake. After the large earthquake, investors do not have any anxiety about the possibility of a prospective large earthquake. Therefore, the saving rates do not change compared to the hypothetical no-earthquake scenario. Secondly, we examined the case of sequential earthquakes with a time lag. This corresponds to a "time lag" scenario. The time lag scenario is constructed based on the latest research on sequential earthquake patterns. In the time lag scenario, a small earthquake occurs in the southern area of the Nankai Trough in the initial period of the simulation. Four years after the small earthquake, a large earthquake (triggered by the small earthquake) occurs in the southeastern area of the Nankai Trough. One year after the first large earthquake, a second large earthquake occurs in the eastern area of the Nankai Trough, which is triggered by the former earthquakes.

The time lag scenario contains two scenarios related to information that the investors have on an earthquake's sequential pattern. One scenario is that investors know that the small earthquake is a precursor to the large earthquakes. Further, the investors know when and where the large earthquakes will occur along the Nankai Trough once the small earthquake occurs. In this scenario, the small earthquake decreases investment by 20% and increases consumption by the same amount in potentially affected areas. After the first large earthquake, 50% of investment decreases, but consumption increases by the same amount in the potentially affected areas where the second large earthquake will hit. After the second large earthquake, there is no investor anxiety over the possibility of a prospective large earthquake. The saving rate, of representative households, returns to the level before the small earthquake occurred. The second scenario is one where investors do not have any information on the earthquake's sequential pattern along the Nankai Trough. Therefore, investors do not know that the small earthquake in the southern area of the Nankai Trough is a precursor to the large earthquakes. In this scenario, the saving rate does not change after the small earthquake occurs. Even after the first large earthquake occurs, the saving rate does not change. Table 1 shows all simulation scenarios conducted in this study.

Table 1. Simulation scenarios

BAU	Business as usual; No-earthquake scenario.
SCE1	The "no time lag" scenario. Several quake focal areas move simultaneously along a wide area of the Nankai Trough.
SCE2	The "time lag" scenario with no information about the possible earthquakes.
SCE3	The "time lag" scenario with perfect information about the possible earthquakes.

4. Simulation results and conclusions

Figure 1 shows monthly real GDP of Japan in each scenario. The simulation results show that investors' anxiety over possible large earthquakes increases total economic loss of a Nankai Trough earthquake through the decrease in investment in potentially affected areas. In SCE3 scenario, investment decreases, while there is an increase in consumption in potentially affected areas after the small earthquake occurs at the initial period of the simulation. The gap between SCE2 and SCE3 expands rapidly one year after the first large earthquake occurs, and reaches its peak when the second large earthquake occurs. In terms of real GDP in Japan, the worst case scenario is SCE3. The simulation result indicates that the economic loss arises and amplifies before the large earthquakes occur due to investor anxiety over a future earthquake. This result is not self-evident, as avoiding investment in risky areas seems to be a common strategy. The degree of increase in the economic loss depends on the degree of change in the investors' preferences, which must be investigated by conducting a questionnaire survey on investor preferences. We also need to conduct a sensitivity analysis of critical parameters in the CGE model to test the robustness of our results.

Regarding the effect of investors' anxiety over Japanese industrial composition, sectors that produce goods for investment proposes, such as metal products, undergo a negative effect on production. Figure 2 shows the real value of production of metal products. On the other hand, Figure 3 shows that food products, which are consumed as final demand goods, undergo increased production during times of investor anxiety. These results reveal that investor anxiety changes the long-term industrial composition. The effect on industrial composition also depends on the degree of change in the investors’ preferences.

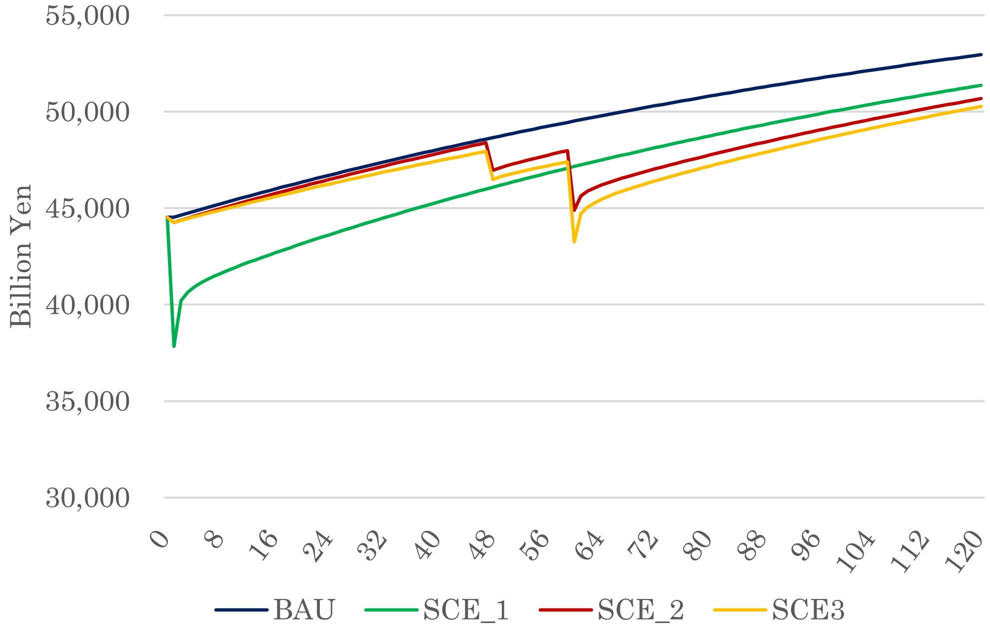

Figure 1 Real monthly GDP of Japan

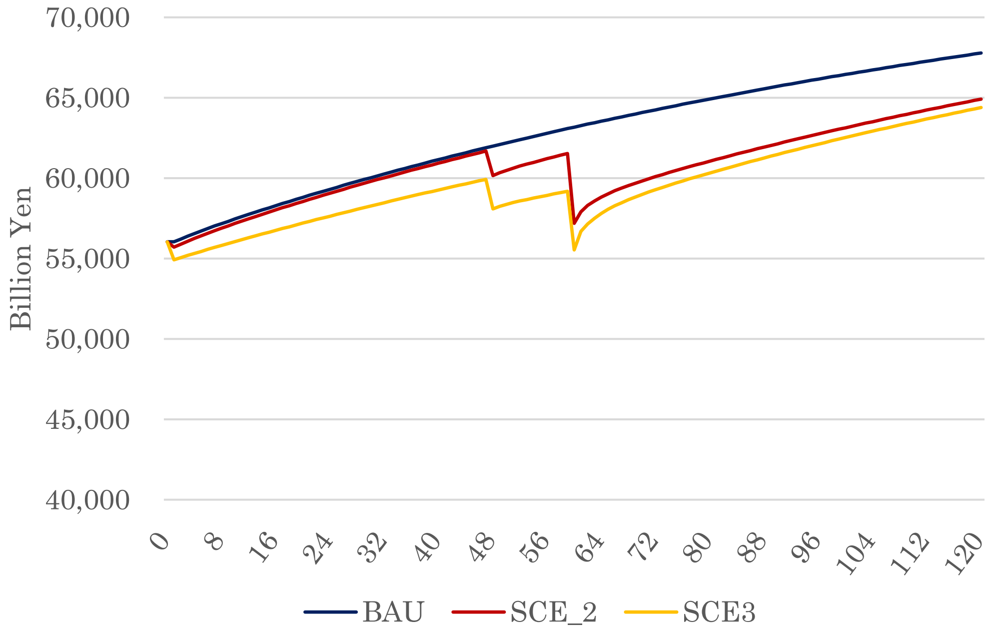

Figure 2 Real value of production (metal products)

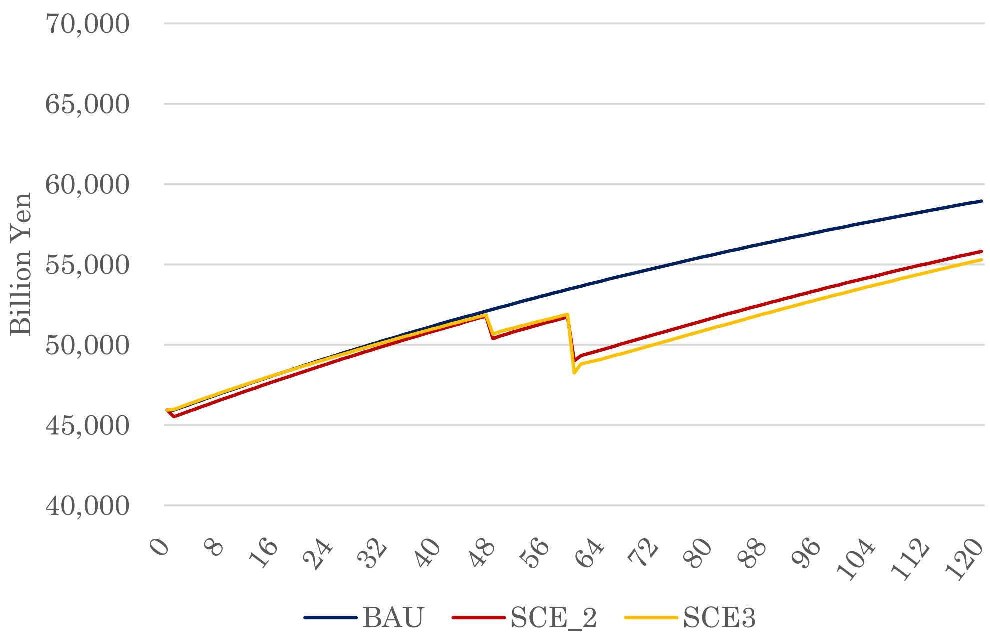

Figure 3 Real value of production (Food products)

References

Hyodo, M, Takane T., Hori and Y., Kaneda (2016) A possible scenario for earlier occurrence of the next Nankai earthquake due to triggering by an earthquake at Hyuga-nada, off southwest Japan. *Earth, Planets And Space*, 10.1186/s40623-016-0384-6.