The effect of an earthquake's sequential pattern on total economic loss caused by earthquakes: a simulation study using multi-regional recursive dynamic Computable General Equilibrium (CGE) models.

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The great East Japan earthquake of 2011 had several quake focal areas, which moved simultaneously, producing an earthquake of magnitude 9.0. The earthquake caused great social and economic loss in Japan. 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 and concluded that there is a 70 % chance of its 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 about an earthquake cycle along the Nankai Trough provides a possible scenario in which a large earthquake is triggered by a small earthquake following a time lag of several years. Historically, earthquakes of magnitude 8.1 were registered in 1944 and 1946. The latter earthquake is considered to be triggered by the former one. 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 was registered, which was characterized by several quake focal areas moving simultaneously. Therefore, when we consider the social and economic impact of a Nankai Trough earthquake, earthquake sequential patterns should be taken into account.

The purpose of this study is to estimate the economic loss caused by the next Nankai Trough earthquake considering the above mentioned sequential pattern with a time lag of several years. Specifically, this study focuses on the effect of investors' expectations or anxiety about possible large earthquakes on their investment behavior. We assume that investors' behavior depends on the sequential pattern of the earthquake. That is, if investors expect a pattern according to which a small earthquake along the Nankai Trough will trigger a large earthquake several years later, the investors could switch their investment from possible affected areas to possible unaffected areas when the small earthquake occurs. This investment decision would be due to the anxiety of the investors about the prospective large earthquake. 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.

In order to begin the examination, we will carefully consider inter- and intra-industry linkages across regions. As the great East Japan earthquake of 2011 exemplified, these linkages lead to economic losses spreading to regions that were initially unaffected; this amplifies the total economic loss. With this in mind, 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 wearing 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 newly investment cross regional and industrial boundaries so as to maximize returns from the investment.

We examined two scenarios with respect to the earthquake sequential pattern. Firstly, only one large earthquake occurs along the Nankai Trough in the initial period considered. 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 this scenario, investors do not be able to change their investment behaviors prior to the earthquake. After the earthquake, investors do not have any anxiety about the possibility of a prospective large earthquake. 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 assumes that investors know that the small earthquake is a precursor to the large earthquakes. Further, it assumes that the investors know when the large earthquakes will occur along the Nankai Trough once the small earthquake occurs. The time lag scenario also assumes that investors change their preferences about their investments. The change leads them to switch their investment from the possible affected areas of the large Nankai Trough earthquake to unaffected areas.

The simulation results show that a time lag of earthquake occurrence leads to an increase in the total economic loss of a Nankai Trough earthquake. In the CGE model, investment moves from productive sectors located in possible affected areas to less productive sectors located in unaffected areas after the small earthquake occurs along the Nankai Trough. The simulation result indicates that the economic loss arises and amplifies before the large earthquakes occur. This result is not self-evident. This is because, 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. Crucially, the investors' behavior is significantly affected by the parameters of the CET function in the CGE model. We investigate this by conducting a questionnaire survey about the relationship between investment location choice and future earthquake risk. We also conduct a sensitivity analysis of critical parameters in the CGE model to test the robustness of our results.