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The Economic Impact of Supply Chain Disruptions from the Great East Japan Earthquake*

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Abstract

The Great East Japan Earthquake of March 11, 2011 had a serious negative economic impact on the Japanese economy. The earthquake substantially reduced production not only in regions directly hit by the earthquake but also in other parts of Japan through supply chain disruptions. We examine the economic impact of the supply chain disruptions immediately following the earthquake using regional input-output (IO) tables, the Japan Industrial Productivity (JIP) database, and other regional statistics. To conduct our analysis, we modify the forward linkage methodology to take into account the first-stage bottleneck effect in the intermediate input of manufacturing production. We also create our own interregional input-output table by combining two different regional IO tables. Our estimates show that the production loss caused by the supply chain disruptions would be a maximum of 0.41% of the country's gross domestic product (GDP). We also analyzed the possible damage mitigating effects of establishing multiple supply chains to cope with potential natural disasters in the future. However, as multiple supply chains may lose production efficiency at the firm level, we need some policies that give incentives to firms which diversify supply chains.

Keywords: Earthquake, Forward linkage, Supply chain, Regional IO tables

JEL classification: L94, Q43, R11, R15

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1. Introduction

The Great East-Japan Earthquake of March 11, 2011 had a serious negative economic impact on the Japanese economy. The destruction in social infrastructure such power plants, roads, railways, and ports resulted in grave negative effects on economic activities in the Tohoku and North-Kanto areas. In addition, as shown in Table 1, it is important to note that the short-term production activities in the private sector were greatly influenced not only in the areas directly hit by the earthquake but also in the other regions. Immediately after the earthquake, in Japan and abroad, and particularly in the automobile and electronic equipment industries, concerns about possible effects on their production activities due to the shortage of essential parts of their product were widely publicized.

[Table1]

Most of the disruption in the supply chain was resolved only a few months later by both dedicated efforts to restore the factories in the disaster-affected area and the substitution of supply sources. However, this incident raised awareness of the adverse effects of the disaster on production activities outside of the disaster-affected areas through supply chain disruptions. Tokui et al. (2012) estimated the indirect damage caused by supply chain disruptions of the Great East-Japan Earthquake using the 2005 version of the interregional IO table provided by the Ministry of Economy, Trade and Industry (METI)[1]. Shimoda and Fujikawa (2012) also conducted a similar analysis using the same IO table. They compared four types of propagation mechanisms from industrial linkages including a hybrid model (the combination of first-stage forward linkage and higher-stage backward linkage), and a bottleneck forward linkage model (only first-stage linkage is counted). Their idea of 'bottleneck forward linkage' is quite similar to

[1] Tokui et al. (2012) also examined the economic impacts of the temporary shutdowns of nuclear power plants.

that of Tokui et al. (2012) and this paper, but they assumed the same bottleneck in both manufacturing and non-manufacturing industries. Tokui et al. (2012) and this paper treat manufacturing and non-manufacturing production differently. Moreover, Tokui et al. (2012) estimated the initial direct damage on production caused by the earthquake by industry, while Shimoda and Fujikawa (2012) assumed that Tohoku area's average decline in industrial production after the earthquake to be direct damage.

Other analyses focused on the relation between the recovery process from the earthquake and the industrial linkage. Wakasugi and Tanaka (2013), for instance, showed that the supply chain disruptions prolonged the recovery processes of production by using the survey on the damage by the Great East-Japan Earthquake -- designed by them and conducted by the Research Institute of Economy, Trade, and Industry. Contrary to their work, Todo, Nakajima, and Matous (2014) showed the possibility of fast recoveries in cases where firms had a variety of supply chains, also using survey data.

While survey data can cast light on individual firm behavior, the IO tables clarify the propagation effects of supply chain disruptions through the linkages across industries.[2] Although we can use the METI's interregional IO table (2005 version) as Tokui et al. (2012) and Shimoda and Fujikawa (2012), the regional division of this IO table is not fine enough for the purpose of our analysis. Three prefectures severely hit by the earthquake, Iwate, Miyagi, Fukushima, are in the Tohoku region with other three prefectures, while another prefecture with huge earthquake damage, Ibaraki, is included in the Kanto region with other ten prefectures. When we rely upon the METI's 2005 interregional IO, the supply chain effects of the four prefectures severely hit by the earthquake are considered to be triggered from all the Tohoku and Kanto regions. To conduct more accurate estimation, we construct our own interregional IO table by combining the METI's

[2] Okiyama, Tokune, and Akune (2012) estimated the economic impacts of the decline in exports from the damaged areas on household income in the damaged area by using the regional IO tables.

2005 interregional IO table with the IO tables at the prefectural level provided by the Central Research Institute of Electric Power Industry (CREPI).

Our key findings are as follows: First, the simple textbook-version forward linkage model only loosely replicates the actual pattern of production decline after the Great East-Japan Earthquake. So we revised this model so that the new one took into account the short-run bottleneck effect of supply chain disruptions in manufacturing production as well as the regional spreading of its effect. We verified that this revised version of the ‘forward linkage model’ was a more appropriate model for explaining the indirect damage caused by the supply chain disruptions.

Second, the indirect effects of the supply chain disruptions were greater than the amount of direct damage. Considering that most of the earthquake-hit factories recovered their production levels within four months after the earthquake, our estimation of the indirect damage of the earthquake was 0.25 percent (first-stage forward linkage effect) and 0.41 percent (total forward linkage effect) of Japan’s GDP as compared to the estimated direct damage to the production of the earthquake being 0.11 percent of GDP.

Third, we evaluate the effects of building multiple supply chains in mitigating the extent of the damage. To this end, our forward linkage model was useful in estimating the size of the indirect damage from supply chain disruptions, in the hypothetical setting where multiple supply chains already existed in the Kanto region. Our calculation found that the provision of multiple supply chains could have mitigated the indirect damage of supply chain disruptions to 60 percent of the size that would occur from such huge natural disasters as the Great East-Japan Earthquake.

In the next section, we explain the basic concept of ‘forward linkage’ in the input-output analysis and how we revised this simple version of the forward linkage model to apply to our analysis. In Section 3, we explain the estimation of direct earthquake damage by industry. We estimate the direct production loss by using regional data from the Economic Census 2009 and damage rate estimated by the Development Bank of Japan as well as other data. The construction of our original interregional IO table is explained in the Appendix. In Section 4, we report our estimates of the indirect production loss caused by supply chain disruptions. We also calculate the effects of building multiple supply chains in mitigating the effects of the damage in this section. In Section 5, we summarize our results.

2. The Estimation Methodology of the Forward Linkage Effect

The basic concept of the 'forward linkage' analysis is clearly explained in Miller and Blair (2009). As is well known, the input-output tables show how the outputs from the industries in the column were used as intermediate goods for the industries in the rows. When we analyze demand-side linkages, we look at the rows of the table to capture the effect. On the other hand, when we analyze the supply-side linkages, we focused on the columns of the table. Let X be the output vector for each sector (X' denotes its transpose), Z be the input-output matrix of the intermediate goods, and V be the factor cost vector (V' denotes its transpose). Then, the relationship along the column of the input-output table can be expressed as:

$$X' = i'Z + V'.$$

Let B be the matrix whose row is equal to each row of the input-output matrix Z, divided by the output of each sector. The entry in the j-th row and in the i-th column of the matrix $B=\{b_{ji}\}$ represents the ratio of the i-th sector's usage of the j-th sector's output to the entire output of the j-th sector. In other words, the matrix B is not a technological input coefficient matrix, but an allocation matrix.

$$B = \begin{bmatrix} Z_{11}/X_1 & \cdots & Z_{1n}/X_1 \\ \vdots & \ddots & \vdots \\ Z_{n1}/X_n & \cdots & Z_{nn}/X_n \end{bmatrix} = \begin{bmatrix} 1/X_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1/X_n \end{bmatrix} \begin{bmatrix} Z_{11} & \cdots & Z_{1n} \\ \vdots & \ddots & \vdots \\ Z_{n1} & \cdots & Z_{nn} \end{bmatrix} = \mathrm{diag}(1/X_j)Z$$

From the equation above, $Z = \left[\mathrm{diag}\left(1/X_j\right)\right]^{-1}B = \mathrm{diag}(X_j)B$ holds. Substituting this into the above equation yields

$$X' = [1 \cdots 1] \begin{bmatrix} X_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & X_n \end{bmatrix} B + V' = X'B + V' \quad (1)$$

Thus the entry in the j-th row and in the i-th column of the matrix $B=\{b_{ji}\}$ shows how the decrease in the output in the j-th entry of X on the right-hand side leads to the decrease in the output of the i-th entry of X' on the left-hand side. In this sense, each entry of matrix B shows the magnitude of the first-stage forward linkage effect. If this propagation of the forward linkage persists, the cumulative sum of the effects can be obtained by using an inverted matrix and solving for X' in (1).

$$X' = V'(I - B)^{-1}$$

We denote the inverted matrix G. That is,

$$G = (I - B)^{-1} = \begin{bmatrix} g_{11} & \cdots & g_{1n} \\ \vdots & \ddots & \vdots \\ g_{n1} & \cdots & g_{nn} \end{bmatrix}$$

Using this new notation to re-write the equation above yields,

$$X' = V' G. \quad (2)$$

Let us denote the i-th entry of X' on the left-hand side X_i. Then from $X_i = V_1 g_{1i} + \cdots + V_j g_{ji} + \cdots + V_n g_{ni}$, we obtain $\frac{\partial X_i}{\partial V_j} = g_{ji}$. The entry in the j-th row and in i-th column of matrix G shows the decrease in the output of the i-th sector in response to a one unit decrease in the fundamental production input (labor and capital), measured in factor income, assigned to the j-th sector. This represents the cumulative effect of forward linkages on the i-th sector's production caused by the constrained factor inputs in the j-th sector.

This is the basic idea of the forward linkage as explained in Miller and Blair (2009). For our purposes, we modify this idea as follows: In our analysis, we replace the supply constraint with the decrease in the outputs of the particular sector (the estimated damage in terms of the value of output). This is easier than tracing back the damage to each fundamental factor of production and converting the loss into factor income units. To express this idea, we take advantage of the following relationships.

$$\frac{\Delta X_i}{\Delta V_j} = g_{ji} \qquad \frac{\Delta X_j}{\Delta V_j} = g_{jj}$$

Combining these two equations, we obtain:

$$\frac{\Delta X_i}{\Delta X_j} = \frac{\Delta X_i}{\Delta V_j} \bigg/ \frac{\Delta X_j}{\Delta V_j} = \frac{g_{ji}}{g_{jj}}$$

This leads to the following.

$$\Delta X_i = \frac{g_{ji}}{g_{jj}} \Delta X_j \tag{3}$$

Using this relationship, the cumulative impact on the i-th sector's production by the forward linkage, or the disrupted supply chain, from the decrease in j-th sector's production due to the earthquake, can be computed by g_{ji}/g_{jj}.

As shown in Appendix 1, by taking advantage of the relationship between the B matrix explained above and the usual input coefficient matrix (which we call the A matrix), we can show that the production technology used in the forward linkage analysis is that of the Cobb-Douglas production function. In other words, when the supply in some intermediate goods decreases, we can always find other intermediate goods as an imperfect substitute for it. For the retail industry, for example, this assumption is realistic; an empty shelf due to a lack of goods from the Tohoku region can be filled by the products from other areas, and the business can continue running. However, in the manufacturing sector, where the final output consists of various parts, substitution would be difficult, at least in the short run. Immediately after the Great East-Japan Earthquake, the inability to find acceptable substitutes for customized parts raised concerns about the supply chain disruptions.

Therefore, we compute the first-stage linkage effect by assuming that the decrease in the total output of a particular manufacturer is driven by a bottleneck in production, or the maximum decrease among all the intermediate goods from other manufacturers. Assuming this strong complementarity among intermediate inputs in manufacturing, the first-stage forward linkage effect can be represented as follows:

$$\left(\frac{\Delta X_i}{X_i}\right)^{1st-stage} = \sum_{j \in M} a_{ji} \cdot \max_{j \in M}\left[\frac{\Delta X_j}{X_j}\right] + \sum_{j \in N} a_{ji} \frac{\Delta X_j}{X_j}, \tag{4}$$

where a_{ji} is an input coefficient in the j-th row and in the i-th column of the standard input coefficient matrix A, and M and N in the subscripts stand for manufacturing industries and non-manufacturing industries, respectively. Here, we assume a Leontief-type production function in the first-stage input output analysis only for the inputs from manufacturing to manufacturing. This means that the input sector with the maximum rate of decline is the bottleneck and forces all the other inputs to fall at the same rate. We do not assume such a bottleneck in the production process of the non-manufacturing sector or non-manufacturing inputs to the manufacturing sector. In computing the cumulative linkage effect after the second stage, we do not consider the bottleneck effect to be this extreme for the second-order effects and later.

As our analysis uses the interregional IO table, there is a further complicated issue in ascertaining the extent to which such a bottleneck effect in manufacturing production significantly matters across regions. In order to obtain relevant information, we calculate the industrial linkage index among regions using our interregional IO table. Table 2 shows the estimated total backward linkage index of machinery industries of the Chubu region[3]. Chubu is a region in Japan where manufacturing industries (machinery industries in particular) are densely located. While this region was not directly hit by the Great East-Japan Earthquake, the manufacturing production of the region declined considerably immediately after the earthquake,

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[3] The total backward linkage index of the j-th industry in r-th region to s-th region as follows. Let l_{ij}^{sr} be the element of the Leontief inverse (total requirement matrix). As we use an interregional IO matrix, the l_{ij}^{sr} represents the total backward linkage coefficient of j-th industry in r-th region to i-th industry in s-th region. We define subtotals of l_{ij}^{sr} for each intermediate input demand directed region s as the total backward linkage j-th industry in r-th region to s-th region.

as shown in Table 1. This is why we focus on the Chubu's backward linkage index to other regions.

[Table2]

Table 2 reveals the strong industrial linkage between the Chubu and Kanto regions, suggesting a vital intermediate input supply from Kanto to Chubu.[4] Since the northern part of the Kanto region, especially Ibaraki prefecture, was severely hit by the earthquake, we consider the substitutability in intermediate input between products in Ibaraki prefecture and those in other prefectures in the Kanto region. Then, we estimate the forward linkage effect under two different assumptions: one where a manufacturing bottleneck occurred in Ibaraki prefecture and spread all over the Kanto region, and the case where the bottleneck effect of Ibaraki prefecture is contained within the prefecture. We examine the projections of regional production declines due to the first-stage forward linkage under the two different assumptions and compare them with the actual decline in manufacturing production in each region within a few months after the earthquake. We find that the estimates based on the first assumption seem to replicate what occurred in reality more closely. This indicates that there is no substitutability in manufacturing production of the Kanto prefectures, at least in the short-run. We use the estimations based on the second assumption for the counterfactual exercise on how much supply chain diversification can mitigate the indirect damage caused by the forward linkage effects of supply chain disruptions. We will get back to the results of the counterfactual exercises in Section 4-4.

3. Estimated Direct Damage by Industry in the Earthquake-affected Area

[4] As for prefectures that are in the Kanto and Chubu regions, see Appendix 2.

In order to estimate the impact of the disrupted supply chain by applying the forward linkage methodology described above, we need to estimate the direct damage from the Great East-Japan Earthquake -- by industry -- in the disaster-affected area. We do this by first estimating the output by industry in each disaster-affected city or town, and then by multiplying these numbers by the estimated damage rates for each city and town.

We can obtain the number of employees by industry in each city and town from the Economic Census 2009, published two years before the Great East-Japan Earthquake. We also use the output per employee ratio and the ratio of real net capital stock per employee by industry, from the country-average data of the Japan Industrial Productivity Database (JIP2010).[5] If we assume that these two ratios for each industry are the same all over Japan, multiplying these ratios and the number of employees by industry in each city and town together gives us the estimated output and real net capital stock for each industry, and for each city and town.

We obtain the damage rate for each city and town by applying the same methodology devised by Tomoyoshi Terasaki of the Development Bank of Japan[6]. He estimates the loss of capital stock in the four prefectures hit by the earthquake (Iwate, Miyagi, Fukushima and Ibaraki), dividing each prefecture into coastal and inland areas. To calculate this estimation, he uses both the human damage rate (the ratio obtained by dividing the sum of the death toll, the number or people missing and evacuees, by the registered population in the area) and the corporate damage rate (the ratio obtained by dividing the number of enterprises reported to be affected by the earthquake by the total number of enterprises 100 or more employees in the area) for each of the coastal and inland areas in these four prefectures. Next, he multiplies the adjustment coefficient obtained by dividing the surveyed (that is, very close to actual) loss of capital stock from the Great Hanshin-Awaji Earthquake in 1995 by the estimated loss of capital

[5] The JIP database consists of 108 industries. The website of the database is **http://www.rieti.go.jp/en/database/JIP2010/index.html**. Fukao et al. (2007) explain how this database was constructed.

[6] See the Development Bank of Japan (2011a, 2011b) for details.

stock, applying the methodology described above to that case. We use the human damage rate for each city and town, and the same numbers for the corporate damage rate and the adjustment coefficient of the area as the Development Bank of Japan (2011a) to obtain the damage rate for each city and town hit by the Great East-Japan Earthquake.

By multiplying the estimated output and real net capital stock by industry at the city and town-level using the above estimated damage rate for each city and town, we obtain the value of the damage (both for the gross output and the real net capital) by industry at the city and town-levels. We then aggregate these values at the city and town-level for three prefectures in the Tohoku region (Iwate, Miyagi and Fukushima) to obtain the estimated damage for the Tohoku region. We do the same for Ibaraki prefecture to obtain the estimated damage for the Kanto region.

[Figure 1, Figure 2]

Figure 1 shows the bar plot of the estimated damage on the real net capital stock for each industry. Each bar is the sum of the Tohoku and the Kanto regions and these two regions are shown in different colors. Figure 2 shows the estimates on the gross output-level damage (at an annual level). In both figures, we can confirm that the damage for the Tohoku region exceeds that of the Kanto region and that the Great East-Japan Earthquake hit the Tohoku region particularly hard. Figure 1 also shows that the damage on the real net capital stock is concentrated in the non-manufacturing sectors, particularly the electricity industry. This reflects the fact that Fukushima Daiichi Nuclear Power Plants were severely damaged and many non-manufacturing firms are located in the coastal area where the tsunami hit hard. On the other hand, Figure 2 shows that not only the non-manufacturing sector (such as commerce) but also the manufacturing sector, in particular the foods industry, suffered a lot in terms of their output.

The annualized direct damage (where annualized means the value assuming the damage after the earthquake persists at the same level for one year) is estimated to be 6.5 trillion Yen.

4. The Magnitude and Propagation of Supply Chain Disruptions

4-1. Construction of the interregional IO table

To apply the forward linkage effect model to the case of supply chain disruptions caused by the Great East-Japan Earthquake, we utilize the interregional input-output table. The basic interregional IO table we rely upon is the Interregional IO Table 2005 compiled by the Ministry of Economy, Trade and Industry (hereafter referred to as the METI-IO 2005), which we used in our earlier version of the paper, Tokui et al. (2012). The METI-IO 2005 is composed of 53 industries and 9 regions and contains not only input transactions within the same region but also input transactions between different regions. However, the METI-IO 2005 has one shortcoming for our purposes: that is, the area covered by each of the 9 regions is not fine enough to accurately estimate the propagation effect of the earthquake. In order to overcome this shortcoming, we modify the METI-IO 2005 by using data from the Prefectural IO Tables 1995 constructed by the Central Research Institute of Electric Power Industry (hereafter referred to as the CRIEPI-IO 1995)[7]. In this way, we have our own interregional IO table separating four prefectures that were severely hit by the earthquake (Iwate, Miyagi, Fukushima, and Ibaraki). The detail of how we constructed this interregional IO table is described in Appendix 2.[8]

4-2. The Regional Propagation Pattern of Supply Chain Disruptions

As mentioned in Section 2, we choose the assumption that there is no substitutability of intermediate inputs supplied in the Kanto region in the short-term. We then compared the

[7] See Hitomi (2008) for details.
[8] Since METI-IO 2005 and our own IO table are'competitive imports' type IO tables, we remove competitive imports from the IO matrix by using import coefficients.

estimated regional propagation pattern of supply chain disruptions under this assumption with the actual decline pattern of regional production of the manufacturing sector immediately after the earthquake (as shown in Table 1). Figure 3 shows the comparison between the estimated regional propagation pattern of first-stage forward linkage under our assumption and the actual production decline immediately after the earthquake (that is, within 20 days after March 11th).

[Figure 3]

Although the estimates based on the non-substitutability assumption are more likely to replicate the actual decline in production than based on the other assumption, Figure 3 shows that our projection of production underestimates the loss of production even under this assumption. We can suggest a few possible reasons why our projections were not closer to actual production loss amounts. First, our estimation of the damage does not include damage to public infrastructure such as roads and shipping ports, as Wakasugi and Tanaka (2013) pointed out, that may have additional effects on production activities in the affected regions. Second, while we compare the first-stage forward linkage with the actual production decline immediately after the earthquake, the second-stage and higher-order linkages to downstream industries may have already taken place. Third, actual input-output linkages of industries may be more complicated. That is, not only forward but also backward linkages may interact each other at the same time[9]. In the Chubu region where automobile-related industries are concentrated, this kind of interaction between forward and backward linkages may be strong, which would explain the greatly understated estimation in this region.

[9] For example, suppose Company A supplying parts to Company B is hit by the earthquake, which stops production activities of both Company A and Company B. Suppose Company B also buys parts from Company C. Even if Company C is free from the earthquake damage and is an upstream firm, the cessation of operations of Company B results in a decline in production of Company C.

On the other hand, when we take a look at Figure 4 that shows the estimated forward linkage effect of the earthquake to the Chubu industries under the same assumption, the estimated industrial propagation pattern of supply chain disruptions is an exact match to what occurred in Chubu immediately after the earthquake. Passenger motor cars and motor vehicle parts are the two industries most heavily affected. The height of each bar in Figure 4 shows the total forward linkage effect, and each bar is made up of two different colors that indicate the part of the first-stage forward linkage and that of cumulative effect after the second-stage. In the two industries most heavily affected by the supply chain disruptions, passenger motor cars and motor vehicle parts, the estimated cumulative effect after the second-stage is much greater than that of the first-stage effect. The former is 1.5 times larger than the latter in the passenger motor cars industry and the former is 2 times larger than the latter in the motor vehicle parts industry. This result confirms the importance of analyzing not only first-stage but also cumulative forward linkages.

[Figure 4]

4-3. The Magnitude of the Effect of Supply Chain Disruptions

Now let us look at the magnitude of supply chain disruptions and its influence on each industry. Both first-stage forward and the total forward linkages are calculated. As explained in the above sections, the first-stage forward linkage is calculated assuming a bottleneck effect in the manufacturing industries and no substitutability within the Kanto region, while higher-order stage forward linkages are calculated without making such special assumptions.

[Figure 5]

Figure 5 shows our calculated results of the first-stage forward linkage effect by industry. A notable feature of the first-stage effect of supply chain disruptions is that the effect is particularly concentrated in the manufacturing industries, while the direct damage from the earthquake itself is highly concentrated in the non-manufacturing industries (as we have seen in Figure 2). In the manufacturing sector, iron and steel, general machinery, electronic components, and motor vehicle parts and accessories suffered a large loss, in addition to the food industry, which suffered some great direct damage. In particular, the automobile-related industries including motor vehicle parts were affected significantly by supply chain disruptions while they suffered relatively less in terms of direct damage from the earthquake itself. This is due to the fact that automobile-related industries depend on a complex division of labor involving a large network of subcontractors. When we aggregate the first-stage forward linkage effects of the supply chain disruptions, the total of this effect amounts to 11.4 trillion Yen per year base. The estimate is about two times as large as that of the direct damage, showing that the supply chain disruption is a crucial factor dragging the Japanese economy significantly after the disaster.

[Figure 6]

Figure 6 shows the total forward linkage effect of supply chain disruptions. We observe that the cumulative effect, assuming the forward linkage effect, continues infinitely[10]. In this calculation, in addition to the industries that suffered greatly from the first-stage effects, the passenger motor cars industry shows large cumulative effects. Each bar in Figure 6 is separated into the three parts by colors indicating direct damage, the first-stage forward linkage effect, and the cumulative effect of second-stage and higher-order forward linkages, respectively. As we can see from the figure, the indirect effect from supply chain disruptions is much larger than the

[10] Although 'infinite' propagation of forward linkage effect seems unrealistic, we can treat 'total forward linkage effect' as an approximation to the cumulative effect of several stages of forward linkage effect.

direct damage in the manufacturing sector. Most impressive of these is the automobile-related industries showing very large second-stage and higher-order forward linkage effects. The estimated damage on a per year basis is as high as 29.5 trillion Yen in gross output.

We should, however, be careful with the interpretation of our estimates. Our estimate is a simple aggregation of numbers on a gross output basis and is based on the unrealistic assumption that the most severe damage to the production immediately after the earthquake would continue for one whole year without any recovery. To obtain more realistic numbers, we should translate the numbers on a gross output basis to a value-added basis and show the actual recovery of production in the earthquake-affected regions. By multiplying the estimated numbers on a gross output basis by the ratio of value-added to output for each industry, we can obtain numbers on a value-added basis[11]. Our estimated direct production damage by the earthquake is equivalent to 0.7 percent of GDP, first-stage forward linkage effect is 1.7 percent of GDP, and total forward linkage effect is 2.7 percent of GDP.

When we normalize the output loss in the damaged area immediately after the earthquake in March to be 100, we can calculate the output loss in the following months from the recovery of manufacturing productions index in the earthquake hit regions. The loss is 62 in April, 33 in May, and 20 in June, showing a pattern of recovery from the earthquake. Therefore, adding two thirds of the damage in March (the quake occurred on March 11th) to the loss over the period between April and June gives us $1.82/12 = (1\times2/3+0.62+0.33+0.20)/12$ of the annualized loss. Converting the annualized estimates to the 4 month estimates reflecting the recovery (from March through June) using this fraction yields a direct output loss by the earthquake of 0.11 percent of GDP, first-stage forward linkage effect of 0.25 percent of GDP, and total forward linkage effect of 0.41 percent of GDP. Results still confirm the large impact of forward linkage effect in comparison with the direct production damage by the earthquake.

[11] Value added ratio to gross output by industry is calculated from the IO table. The value added damage is then divided by Japan's 2011 GDP to have the value of damages relative to GDP.

4-4. Effects of Establishing Multiple Supply Chains in Mitigating Damage

Since we observe the significant damage of forward linkage effects caused by supply chain disruptions, it is worthwhile to consider how the damage could be mitigated through establishing multiple supply chains. To that end, we first need to estimate the benefits of keeping multiple supply chains in the case of natural disasters. How large would the damage from forward linkage effects be if we could rely on multiple supply chains from different places in the Kanto region? Figure 7 and Figure 8 show respectively the first-stage effect and the total forward linkage effect under such a hypothetical situation.

[Figure 7]

Comparing Figure 7 with Figure 5, we see that the possibility of substitution of parts supply within the Kanto and the Tohoku regions significantly reduces the first-stage forward linkage effect. In this case, the first-stage forward linkage effect is estimated to be 6.2 trillion Yen (on an annual basis), which is 54 percent of the case without the possibility of substitution. For the industry-level breakdown, while the effect on the electronic components industry still exceeds that of the foods industry, other industries including automobile-related industries show relatively smaller effects than the foods industry.

[Figure 8]

Figure 8 shows the total forward linkage effects where substitution in parts supply within the Kanto region is possible. The impact on the automobile-related industries becomes larger due to their complicated interdependence. However, the magnitude is still similar to the foods industry, which experienced large direct damage, and to some of the non-manufacturing industries, which also suffered relatively large losses (such as commerce and construction). The total forward linkage effect is 18.1 trillion Yen (on an annual basis), which is slightly greater than the 60% corresponding value in Figure 6, with no substitution within the Kanto region.

The bottom line is that by only diversifying the parts supply sources to two different places we can mitigate the forward linkage effect from supply chain disruptions to 60 percent of the level of the case of such huge natural disasters as the Great East-Japan Earthquake. Applying this result to the estimated effects from March through June after the 3.11 earthquake, the diversification in the supply of parts can mitigate the first-stage forward linkage effect to 0.19 percent of GDP, and the total forward linkage effect to 0.27 percent of GDP, which are smaller than normal fluctuations over the business cycle. The benefit from this diversification is important when the recovery from earthquake damage takes time and for industries with a complex network of supply chains such as the case of automobile-related industries.

5. Concluding Remarks

We focused on the phenomenon of supply chain disruptions that occurred immediately after the Great-East Japan Earthquake and examined the applicability of the 'forward linkage model' to this phenomenon. To do this, we estimated each prefecture's direct damage from the earthquake by industry and constructed our own interregional IO table in which Japan was divided into four prefectures severely hit by the earthquake and nine other regions. When we applied the 'forward linkage model' to these data, we found that the simple textbook-version forward linkage model only loosely fit the actual pattern of production decline after the earthquake. So we revised the model so that it took into account short-run bottleneck effects of supply chain disruptions in manufacturing production as well as the regional spread of its effect. We verified that this revised version of the 'forward linkage model' was a more appropriate model to explain the phenomenon.

Using this revised version of the 'forward linkage model', we calculated the extent of the indirect damage caused by the supply chain disruptions and found that the indirect damage was quite significant compared to the direct damage. Only the first-stage effect of supply chain disruptions was two times greater than the amount of direct damage and the cumulative effect of supply chain disruptions could become much larger. Considering that most of the earthquake-hit factories recovered its pre-earthquake production levels within four months after the earthquake, our estimation of the indirect damage of the earthquake was 0.25 percent (first-stage forward linkage effect) and 0.41 percent (total forward linkage effect) of Japan's GDP as compared to the estimated direct damage to the production of the earthquake being 0.11 percent of the GDP.

Finding such significant damage caused by the forward linkage effect of supply chain disruptions emphasized the importance of establishing multiple supply chains. To this end our forward linkage model was useful in calculating the size of indirect damage of supply chain disruptions in the case of our hypothetical setting where multiple supply chains were already established in the Kanto region. Our calculation found that such provision of multiple supply chains could have mitigated the indirect damage of supply chain disruptions to 60 percent of the level caused by such huge natural disasters as the Great East-Japan Earthquake.

Though Japan has been struck by many severe earthquakes in the past, the Great East-Japan Earthquake is unique in the sense that it hit large areas of the Tohoku and the Kanto regions where complex linkages of supply chains exist. This situation raised concerns about the propagation of supply chain disruptions immediately after the earthquake. Our calculation confirms that such concerns are valid because the estimated decline in production in Japan caused by forward linkage effects from supply chain disruptions is much larger than direct earthquake damage. The experience of the Great East-Japan Earthquake brings to light the importance of damage mitigation of natural disasters. Our estimates suggest that the benefit of supply chain diversification is quite significant.

Our estimated supply chain disruption is relatively small compared to our previous estimation in Tokui et al. (2012). In our previous work we use the METI's 2005 version interregional IO table, which separates Japan into nine regions. The supply chain effects from four prefectures severely hit by the earthquake -- Iwate, Miyagi, Fukushima in the Tohoku region, and Ibaraki in the Kanto region -- are considered to be triggered from all the Tohoku and Kanto regions. This limited data availability of the IO table brings about an overestimation of the effect of supply chain disruptions. Considering the huge budget deficits and future disasters in Japan, our study implies that we need more accurate and sophisticated regional data to avoid overestimation in economic impacts of the large natural disasters.

Lastly we should mention two limitations of our work. First, the accuracy of our revised version of the 'forward linkage model' that takes into account the short-run bottleneck effect in manufacturing production is dependent on the granularity of industrial classifications of the IO table. For example, the most noted case of supply chain disruptions in the Great East-Japan Earthquake pertains to the supply of microprocessors from a certain company located in Ibaraki. However, when we count its supply chain disruptions in broad industrial classifications, the estimated effect appears smaller, despite our consideration of short-run bottleneck effect. Second, our estimation of indirect damage depends on the speed of the recovery from the direct damage in earthquake-hit regions. As we mentioned previously, Todo, Nakajima, and Matous (2014) suggests that the speed of recovery is faster in companies with wide supply chain networks to other regions. In that case, having supply chain networks has two kinds of effects; the negative effect is greater short-run damage from supply chain disruptions and the positive side is accelerated recovery from direct damage of the earthquake. However, as far as our industry-level analysis concerned, we do not have evidence to state that the recovery speed is positively correlated with the degree of industrial linkage to other regions and we recommend that firms should diversify their supply chains to avoid supply chain disruptions due to the natural disasters. However, as diversification of supply chains may lose production efficiency, some policy subsidies are needed.

Appendix 1: Substitutability in the Standard Forward Linkage Model

We will explain the assumption about the production function on which the forward linkage model described in Section 2 is based. Starting with the equation that yields the forward linkage.

$$X' = X'B + V'$$

We then take the difference from both sides of the equation, it yields,

$$\Delta X' = \Delta X'B + \Delta V'.$$

Post-multiplying $\mathrm{diag}(1/X_j)$, we have,

$$\Delta X' \cdot \mathrm{diag}(1/X_j) = \Delta X' \cdot \mathrm{diag}(1/X_j) \cdot \mathrm{diag}(X_j) \cdot B \cdot \mathrm{diag}(1/X_j) + \Delta V' \cdot \mathrm{diag}(1/X_j).$$

Here, the term $\mathrm{diag}(X_j) \cdot B \cdot \mathrm{diag}(1/X_j)$ corresponds to the standard input coefficient matrix A.

Thus we can rewrite the equation above such that,

$$\Delta X' \cdot \mathrm{diag}(1/X_j) = \Delta X' \cdot \mathrm{diag}(1/X_j) \cdot A + \Delta V' \cdot \mathrm{diag}(1/X_j).$$

In other words, the following will hold,

$$\begin{bmatrix} \frac{\Delta X_1}{X_1} & \cdots & \frac{\Delta X_n}{X_n} \end{bmatrix} = \begin{bmatrix} \frac{\Delta X_1}{X_1} & \cdots & \frac{\Delta X_n}{X_n} \end{bmatrix} A + \begin{bmatrix} \frac{\Delta V_1}{X_1} & \cdots & \frac{\Delta V_n}{X_n} \end{bmatrix}$$

Let a_{ji} be the entry in the j-th row and the i-th column of the input coefficient matrix A. Then, the effect of the change in the first term of the right-hand side on the i-th sector in the left-hand side can be computed as,

$$\frac{\Delta X_i}{X_i} = \sum_{j=1}^{n} a_{ji} \frac{\Delta X_j}{X_j} \qquad \text{(A-1)}$$

Let us rewrite X_j on the right-hand side as Z_j to clarify that it is an input, then the equation becomes,

$$\Delta \log X_i = \sum_{j=1}^{n} a_{ji}\ \Delta \log Z_j.$$

In other words,

$$X_i = \mathrm{const} \cdot Z_1^{a_{1i}} \cdots Z_n^{a_{ni}}.$$

Therefore, we can see that this model is based on the Cobb-Douglas production function with coefficients a_{ji}.

Appendix 2: Constructing Interregional IO Table to Estimate the Effect of Supply Chain Disruptions by the Great East-Japan Earthquake

In this appendix, we explain how we created the interregional IO table for the purpose of our analysis.

1. METI's interregional IO table 2005 (METI-IO 2005) and its classifications of Japanese regions

The METI-IO consists of 9 regions and 53 industries and shows economic transactions between industries within the region and between different regions. The classifications of Japanese regions follow METI's regional bureaus, which cover the following prefectures.

Hokkaido Bureau of Economy, Trade and Industry：Hokkaido

Tohoku Bureau of Economy, Trade and Industry：Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima

Kanto Bureau of Economy, Trade and Industry：Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa, Niigata, Yamanashi, Nagano, Shizuoka

Chubu Bureau of Economy, Trade and Industry：Toyama, Ishikawa, Gifu, Aichi, Mie

Kinki Bureau of Economy, Trade and Industry： Fukui, Shiga, Kyoto, Osaka, Hyogo, Nara, Wakayama

Chugoku Bureau of Economy, Trade and Industry：Tottori, Shimane, Okayama, Hiroshima, Yamaguchi

Shikoku Bureau of Economy, Trade and Industry：Tokushima, Kagawa, Ehime, Kochi

Kyushu Bureau of Economy, Trade and Industry：Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, Kagoshima

Okinawa Bureau of Economy, Trade and Industry：Okinawa

As the above definitions of the Tohoku and the Kanto regions are too broad, they include not only prefectures severely hit by the Great East -Japan Earthquake but also other prefectures. In order to conduct a reliable analysis of the effect of the Great East -Japan Earthquake, we need to separate the severely damaged prefectures from the other prefectures. Therefore we extract Iwate, Miyagi, Fukushima and Ibaraki prefectures, where the earthquake caused severe damage from other prefectures in the interregional IO table using other information. The following is the regional classification of our own interregional IO table.

1.Hokkaido region, 2.Iwate prefecture,3.Miyagi prefecture,4.Fukushima prefecture,5.Ibaraki Prefecture,6.Tohoku region except Iwate, Miyagi, and Fukushima prefectures,7.Kanto region except Ibaraki prefecture,8.Chubu region,9.Kinki region,10.Chugoku region,11.Shikoku region,12.Kyushu region,13.Okinawa region

2. Modification of the METI-IO 2005 using the CRIEPI-IO 1995

The other sources of information we use to modify METI-IO 2005 are multiregional IO tables provided by Central Research Institute of Electric Power Industry (CRIEP-IO 1995).[12] Figure A1 shows the basic structure of the CRIEP-IO. In the CRIEP-IO each prefecture's 'transfer to other regions' and 'transfer from other regions' are divided into transactions to 47 other prefectures. Using CRIEPI, we know the transactions from Industry A in Prefecture Z to Prefecture Y. However, we are not able to know which industry in Prefecture Y the intermediate product from Industry A in Prefecture Z is shipped. The method to convert this type of multiregional IO tables into true interregional IO table is explained in Miller and Blair (2009).

A[12] As for Prefectural Level Input-Output Tables, see Hitomi (2008).

Although this method can create a new interregional IO table based on the multiregional CRIEPI-IO 1995, we use this interregional IO table for the data to modify the METI-IO 2005. The main reason that we adopt this approach is that the CRIEPI-IO is based on transactions in 1995 and outdated compared to the METI-IO that is based on transactions in 2005. In the following, we describe our detailed method to create our own interregional IO table.

Figure A1

Intermediate inputs z_{ij}	Final demand Fd_i	Transfer to other regions TX_{ip}	Transfer from other regions $-TM_{ip}$	Exports-imports EX_i-IM_i	Output X_i
Gross value added V_{ij}					
Output X_j					

We denote trade values of Industry i in Region r which is sold to Region s as TM_i^{rs}. Then, the matrix describing transactions from Region r to Region s is as follows;

$$TM^{rs} = \begin{bmatrix} TM_1^{rs} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & TM_n^{rs} \end{bmatrix}$$

where, i =1,2,……,n.

When we define A^s as an input coefficient in Region s, $TM_i^{rs} A^s$ is

$$TM^{rs}A^s = \begin{bmatrix} TM_1^{rs}a_{11}^s & \cdots & TM_1^{rs}a_{n1}^s \\ \vdots & \ddots & \vdots \\ TM_n^{rs}a_{n1}^s & \cdots & TM_n^{rs}a_{nn}^s \end{bmatrix} \quad \text{(A-2).}$$

$TM_i^{rs} A^s$ is Z^{rs} in the regional IO tables. As we obtain TM^{rs},A^s from CRIEPI-IO, we are able to transform CRIEPI to regional IO tables. This transformation implies that values of goods of industry i in region r, which is sold to region s, are allocated to each industry based on the input coefficients in region s.

Figure A2

SB^{11}	SB^{12}	SB^{13}
SB^{21}	SB^{22}	SB^{23}
SB^{31}	SB^{32}	SB^{33}

The essence of our regional IO tables is described in Figure A2. Figure A2 is the regional IO tables in three regions. SB^{rs} is a matrix, which describes transactions from region r to region s. To construct a diagonal matrix (that is, SB^{11},SB^{22},SB^{33}), we use transaction tables in CRIEPI-IO. We estimate off-diagonal matrix following Equation (A2).

3. Harmonization of industry classifications

As CRIEPI-IO has different industry classifications from METI-IO, we convert the industry classifications of CRIEPI-IO to those of METI-IO by using the following corresponding table of the two industry classifications shown in Table A1.

4. Estimation of transactions of the four prefectures

We separate Iwate, Miyagi, and Fukushima prefectures from the Tohoku region and Ibaraki from the Kanto region by using the transactions data between prefectures in CRIEPI-IO. By using a three-region model in Figure A2, we explain how we separate data from the METI-IO Tables. Suppose that we separate Region 2 in Table A2 into two regions. This separation transforms the three-region model into a four-region model as in the upper figure in Figure A3. In the lower figure in Figure A3, we reclassify each block by how they were transformed.

First, blocks written showing 'IV' remain the same as the before they were transformed.

Second, we estimate transactions in blocks showing 'I', 'II', and 'III'. We define SZ^{rs} in Figure A3 as the following matrix;

$$SZ^{rs} = \begin{bmatrix} z_{11}^{rs} & \cdots & z_{1n}^{rs} \\ \vdots & \ddots & \vdots \\ z_{n1}^{rs} & \cdots & z_{nn}^{rs} \end{bmatrix}.$$

In blocks showing 'I', we calculate the industry's share in the transactions by considering the sum of transactions between industries in Region 2 to be the control total. For example, in SZ^{2A2A} in the upper figure in Figure A3, the share of transactions in this block is expressed as follows;

$$Share^{2A2A} = \begin{bmatrix} \frac{z_{11}^{2A2A}}{z_{11}^{2A2A} + z_{11}^{2A2B} + z_{11}^{2B2A} + z_{11}^{2B2B}} & \cdots & \frac{z_{1n}^{2A2A}}{z_{1n}^{2A2A} + z_{1n}^{2A2B} + z_{1n}^{2B2A} + z_{1n}^{2B2B}} \\ \vdots & \ddots & \vdots \\ \frac{z_{n1}^{2A2A}}{z_{n1}^{2A2A} + z_{n1}^{2A2B} + z_{n1}^{2B2A} + z_{n1}^{2B2B}} & \cdots & \frac{z_{nn}^{2A2A}}{z_{nn}^{2A2A} + z_{nn}^{2A2B} + z_{nn}^{2B2A} + z_{nn}^{2B2B}} \end{bmatrix}$$

Each factor in SB^{22} in Figure 2A is a product in a factor in share matrix and transaction between regions. Then, SB^{22} is expressed as the following matrix;

$$SB^{22} = \begin{bmatrix} mz_{11}^{22} & \cdots & mz_{1n}^{22} \\ \vdots & \ddots & \vdots \\ mz_{n1}^{22} & \cdots & mz_{nn}^{22} \end{bmatrix}$$

Then, SZ^{2A2A} in our regional IO is

$$\begin{bmatrix} \frac{z_{11}^{2A2A}}{z_{11}^{2A2A}+z_{11}^{2A2B}+z_{11}^{2B2A}+z_{11}^{2B2B}} mz_{11}^{22} & \cdots & \frac{z_{1n}^{2A2A}}{z_{1n}^{2A2A}+z_{1n}^{2A2B}+z_{1n}^{2B2A}+z_{1n}^{2B2B}} mz_{1n}^{22} \\ \vdots & \ddots & \vdots \\ \frac{z_{n1}^{2A2A}}{z_{n1}^{2A2A}+z_{n1}^{2A2B}+z_{n1}^{2B2A}+z_{n1}^{2B2B}} mz_{n1}^{22} & \cdots & \frac{z_{nn}^{2A2A}}{z_{nn}^{2A2A}+z_{nn}^{2A2B}+z_{nn}^{2B2A}+z_{nn}^{2B2B}} mz_{nn}^{22} \end{bmatrix}.$$

As transactions in columns are separated in blocks showing 'II', we have to maintain consistency in transactions in columns. In this case, the control total is the total inputs at the industry and regional levels. For example, a share matrix in block SZ^{2A1} is

$$Share^{2A1} = \begin{bmatrix} \frac{z_{11}^{2A1}}{z_{11}^{2A1}+z_{11}^{2B1}} & \cdots & \frac{z_{1n}^{2A1}}{z_{1n}^{2A1}+z_{1n}^{2B1}} \\ \vdots & \ddots & \vdots \\ \frac{z_{n1}^{2A1}}{z_{n1}^{2A1}+z_{n1}^{2B1}} & \cdots & \frac{z_{nn}^{2A1}}{z_{nn}^{2A1}+z_{nn}^{2B1}} \end{bmatrix}.$$

By using the above share matrix and conducting similar calculations to the case in block 'I', we estimate the transactions in our regional IO tables.

As transactions in rows are separated in blocks showing 'III', we have to keep consistency in transactions in rows. In this case, the control total is the total outputs at the industry and regional levels. For example, a share matrix in block $SZ^{12A\,1}$ is

$$Share^{12A} = \begin{bmatrix} \frac{z_{11}^{12A}}{z_{11}^{12A}+z_{11}^{12B}} & \cdots & \frac{z_{1n}^{12A}}{z_{1n}^{12A}+z_{1n}^{12B}} \\ \vdots & \ddots & \vdots \\ \frac{z_{n1}^{12A}}{z_{n1}^{12A}+z_{n1}^{12B}} & \cdots & \frac{z_{nn}^{12A}}{z_{nn}^{12A}+z_{nn}^{12B}} \end{bmatrix}.$$

By using the above share matrix and making similar calculation to the case in block 'I', we estimate transactions in our regional IO tables.

Applying the above estimations to METI-IO and using the transactions data in CRIEPI-IO, we construct our own regional IO tables to study the direct and indirect effects of damages in the Great East-Japan Earthquake.

Table A1

METI	CREPI
Agriculture, forestry and fishery	Agriculture
Agriculture, forestry and fishery	Forestry
Agriculture, forestry and fishery	Fishery
Mining	Mining
Coal mining , crude petroleum and natural gas	Mining
Beverages and Foods	Foods, Bevergaes, and Tabacco
Textile products	Textile products
Wearing apparel and other textile products	Wearing apparel and other textile products
Timber, wooden products and furniture	Timber and wooden products
Timber, wooden products and furniture	Furniture
Pulp, paper, paperboard, building paper	Pulp, paper, paperboard, building paper
Printing, plate making and book binding	Printing, plate making and book binding
Chemical basic product	Chemical products
Synthetic resins	Chemical products
Final chemical products	Chemical products
Medicaments	Chemical products
Petroleum and coal products	Petroleum and coal products
Plastic and rubber products	Plastic products
Plastic and rubber products	Rubber Products
Ceramic, stone and clay products	Ceramic, stone and clay products
Iron and steel	Iron and steel
Non-ferrous metals	Non-ferrous metals
Metal products	Metal products
General machinery	General machinery
Machinery for office and service industry	Electric Machinery
Electrical devices and parts	Electric Machinery
Other electrical machinery	Electric Machinery
Household electric appliances	Electric Machinery
Household electronics equipment	Electric Machinery
Electronic computing equipment and accessory equipment of electronic computing equipment	Electric Machinery
Electronic components	Electric Machinery
Passenger motor cars	Transportation equipments
Other cars	Transportation equipments
Motor vehicle parts and accessories	Transportation equipments
Other transport equipment	Transportation equipments
Precision instruments	Precision instruments
Miscellaneous manufacturing products	Miscellaneous manufacturing products
Reuse and recycling	Reuse and recycling
Construction	Construction
Electricity	Electricity
Gas and heat supply	Gas and heat supply
Water supply and waste disposal business	Water supply and waste disposal business
Commerce	Commerce
Finance and insurance	Finance and insurance
Real estate	Real estate and housing
House rent (imputed house rent)	Real estate and housing
Transportion services	Transportion services
Other information and communications	Other information and communications
Information services	Information services
Public administration	Public administration
Education and research	Education
Education and research	Research
Medical service, health, social security and nursing care	Medical service, health, social security and nursing care
Medical service, health, social security and nursing care	Other public services
Advertising services	Advertising services
Goods rental and leasing services	Goods rental and leasing services
Other business services	Other business services
Personal services	Entertainment
Personal services	Eating and drinking places
Personal services	Accommodation
Personal services	Other personal services
Others	Others

Figure A3

SZ^{11}	SZ^{12A}	SZ^{12B}	SZ^{13}
SZ^{2A1}	SZ^{2A2A}	SZ^{2A2B}	SZ^{2A3}
SZ^{2B1}	SZ^{2B2A}	SZ^{2B2B}	SZ^{2B3}
SZ^{31}	SZ^{32A}	SZ^{32B}	SZ^{33}

IV	III	III	IV
II	I	I	II
II	I	I	II
IV	III	III	IV

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Table 1. Actual production decline immediately after the Great East-Japan Earthquake by region

		Index of Industrial Production(Feb-March,2011) (2010=100)		Index of Industrial Production(March,2011) (2010=100)		1-(b)/(a)
		Feb.2011	March.2011	Before March 10(a)	After March 10(b)	
Hokkaido		101.5	98.9	101.5	97.6	0.04
Tohoku		103.9	65.2	103.9	45.9	0.56
	Iwate	103	65.9	103	47.4	0.54
	Miyagi	104.1	48.6	104.1	20.9	0.80
	Fukushima	97.5	69.8	97.5	56.0	0.43
Kanto		101.4	78.4	101.4	66.9	0.34
	Ibaragi	109.9	66.7	109.9	45.1	0.59
Chubu		103.3	85.3	103.3	76.3	0.26
Kinki		108.2	102.1	108.2	99.1	0.08
Chugoku		102.3	94.1	102.3	90.0	0.12
Shikoku		103.6	102.8	103.6	102.4	0.01
Kyushu		103.2	91	103.2	84.9	0.18

(Source) Regional IIP provided by each branch of Ministry of Economy, Trade, and Industry

(Note) The decline in industrial production immediately after the earthquake, March 11, (b) is calculated assuming the production level in ten days before March 10(a) is the same as that of February 2011. Thus, the index of industrial production of March 2011 is the weighted average of production level of ten days before March 10 and that of twenty days after March 11.

Table 2. The total backward linkage index from machinery industries in the Chubu region

	Hokkaido	Tohoku				Kanto		Chubu	Kinki	Chugoku	Shikoku	Kyushu	Okinawa
		Iwate	Miyagi	Fukushima	Other Tohoku	Ibaraki	Other Kanto						
General Machinery	0.004	0.003	0.005	0.003	0.003	0.013	0.135	1.698	0.122	0.045	0.009	0.018	0.000
Electric Machinery	0.007	0.007	0.013	0.008	0.006	0.010	0.171	1.659	0.133	0.041	0.008	0.021	0.000
Transportation Machinery	0.005	0.003	0.004	0.003	0.002	0.007	0.136	2.258	0.068	0.057	0.005	0.018	0.000
Precision Machinery	0.004	0.009	0.007	0.009	0.009	0.010	0.213	1.554	0.099	0.017	0.006	0.007	0.000

(Note) Calculated from our original Interregional IO table.

Figure 1 Loss of real net capital stock in the Tohoku and Kanto regions

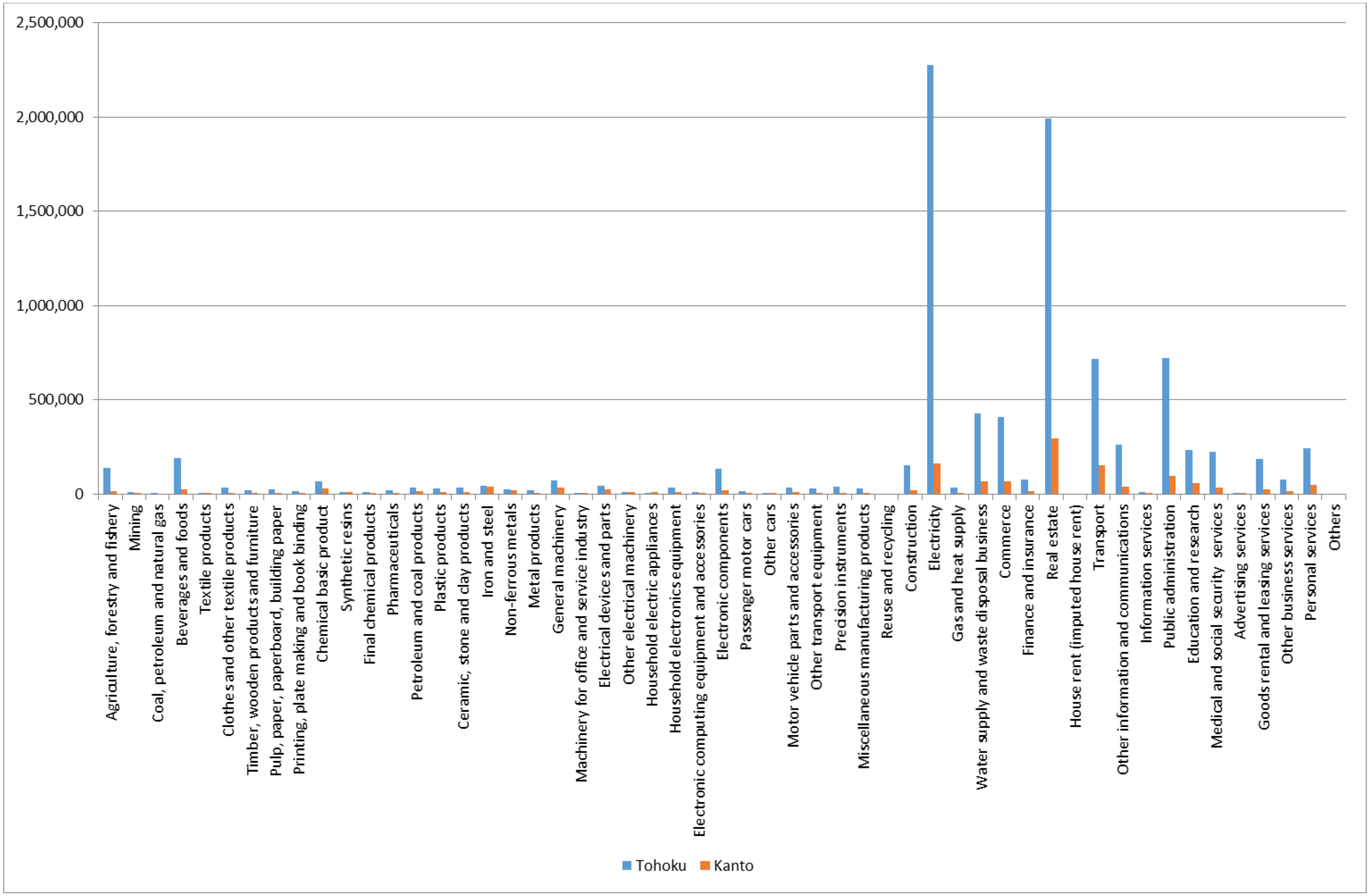

Figure 2 Gross output lost by the direct damage of Great East-Japan Earthquake in the Tohoku and Kanto regions

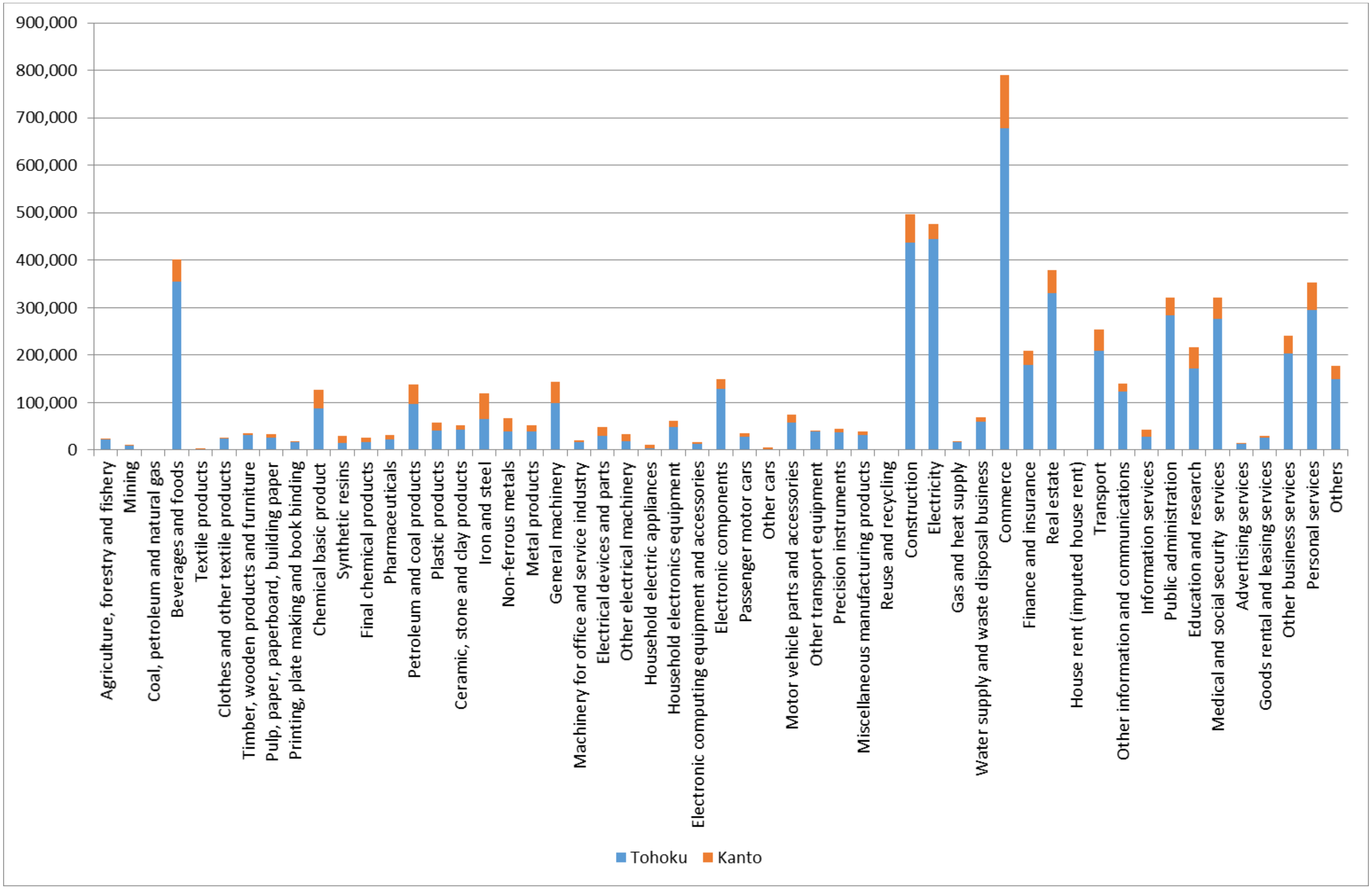

Figure 3. Comparison of our estimates (the first-stage forward linkage effect) with actual production decline by region

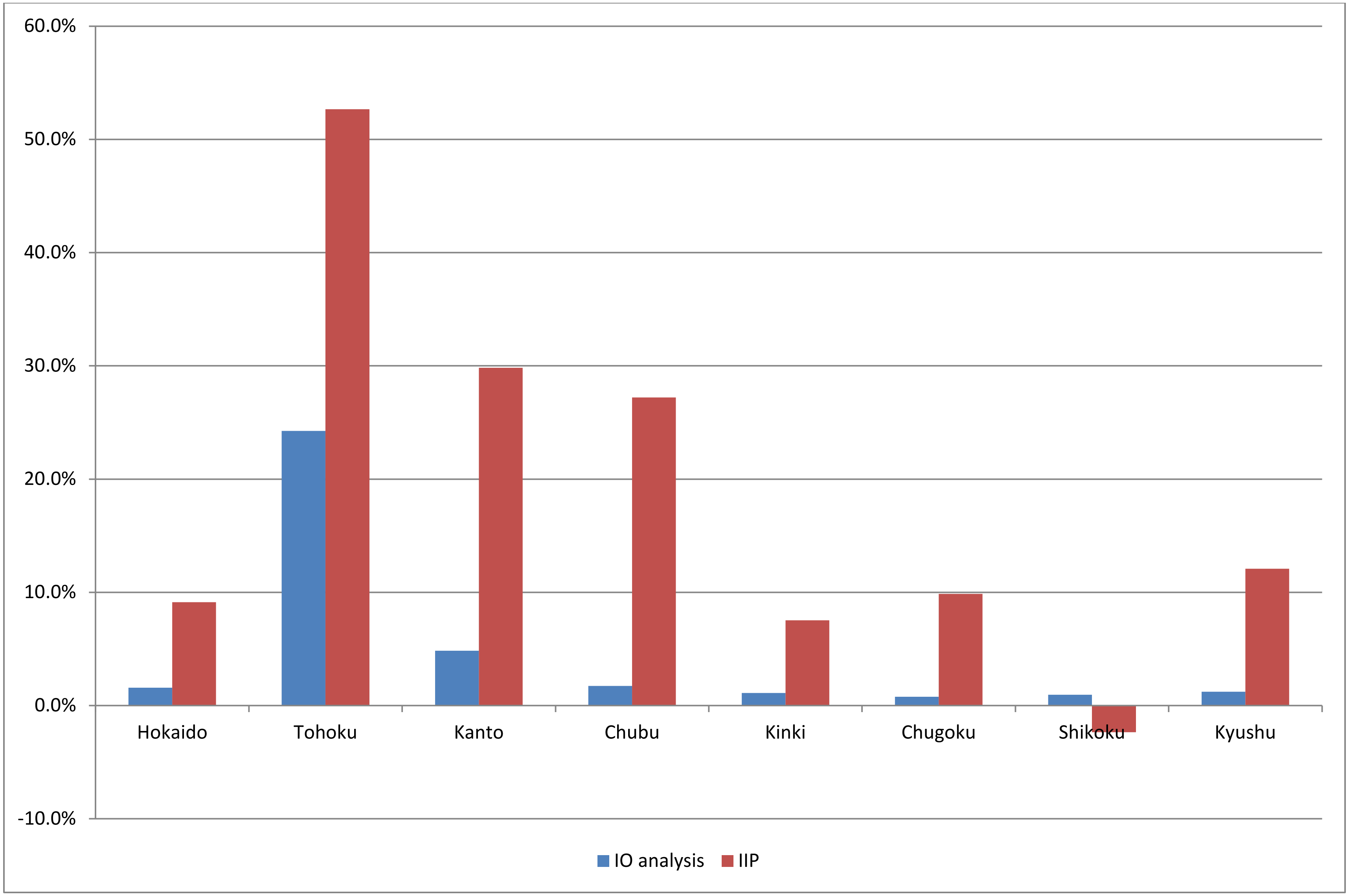

Figure 4. Estimated forward linkage effect to Chubu region's industries

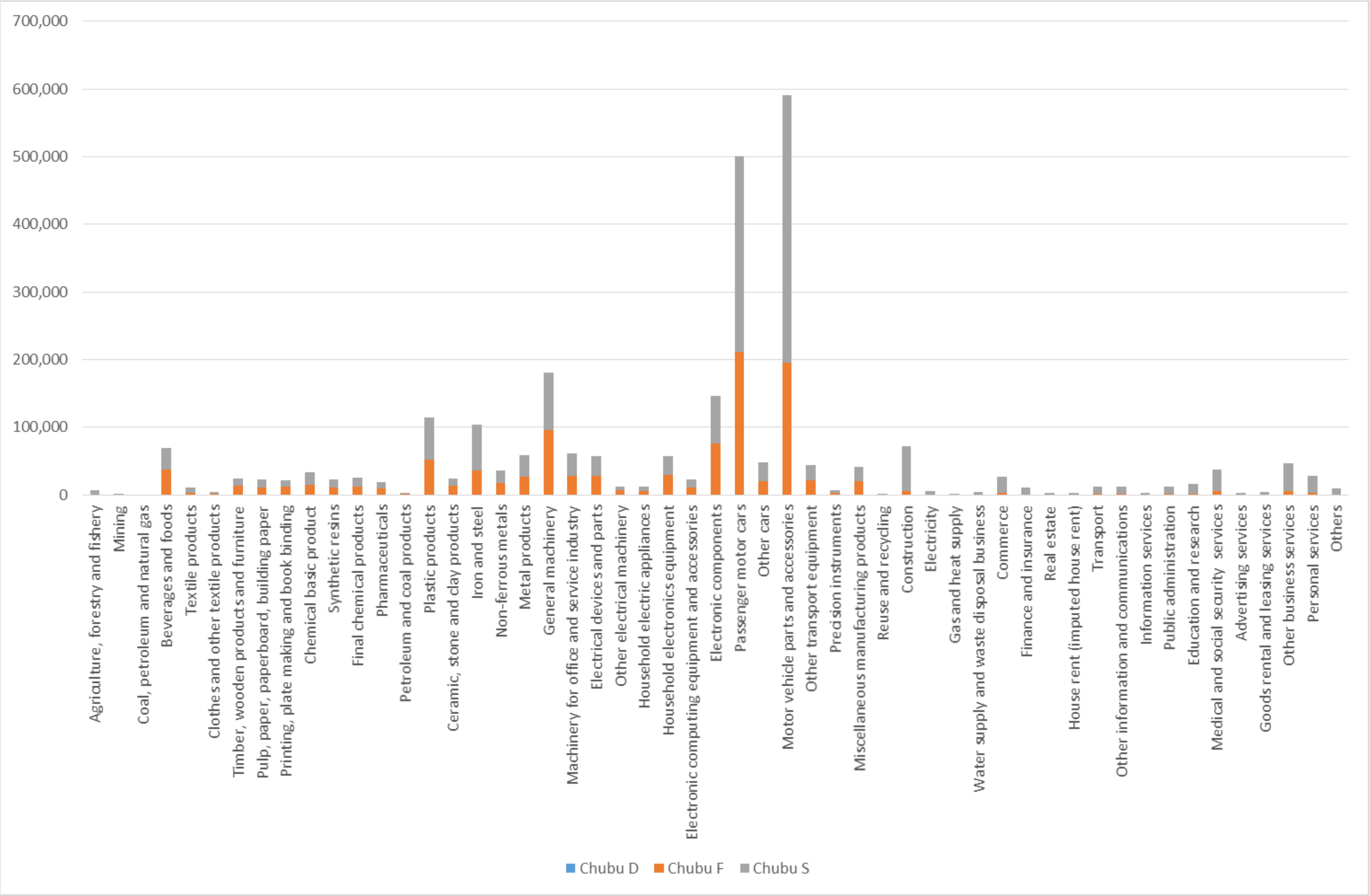

Figure 5. The first-stage forward linkage effect by industry (non-substitutability within the Kanto region)

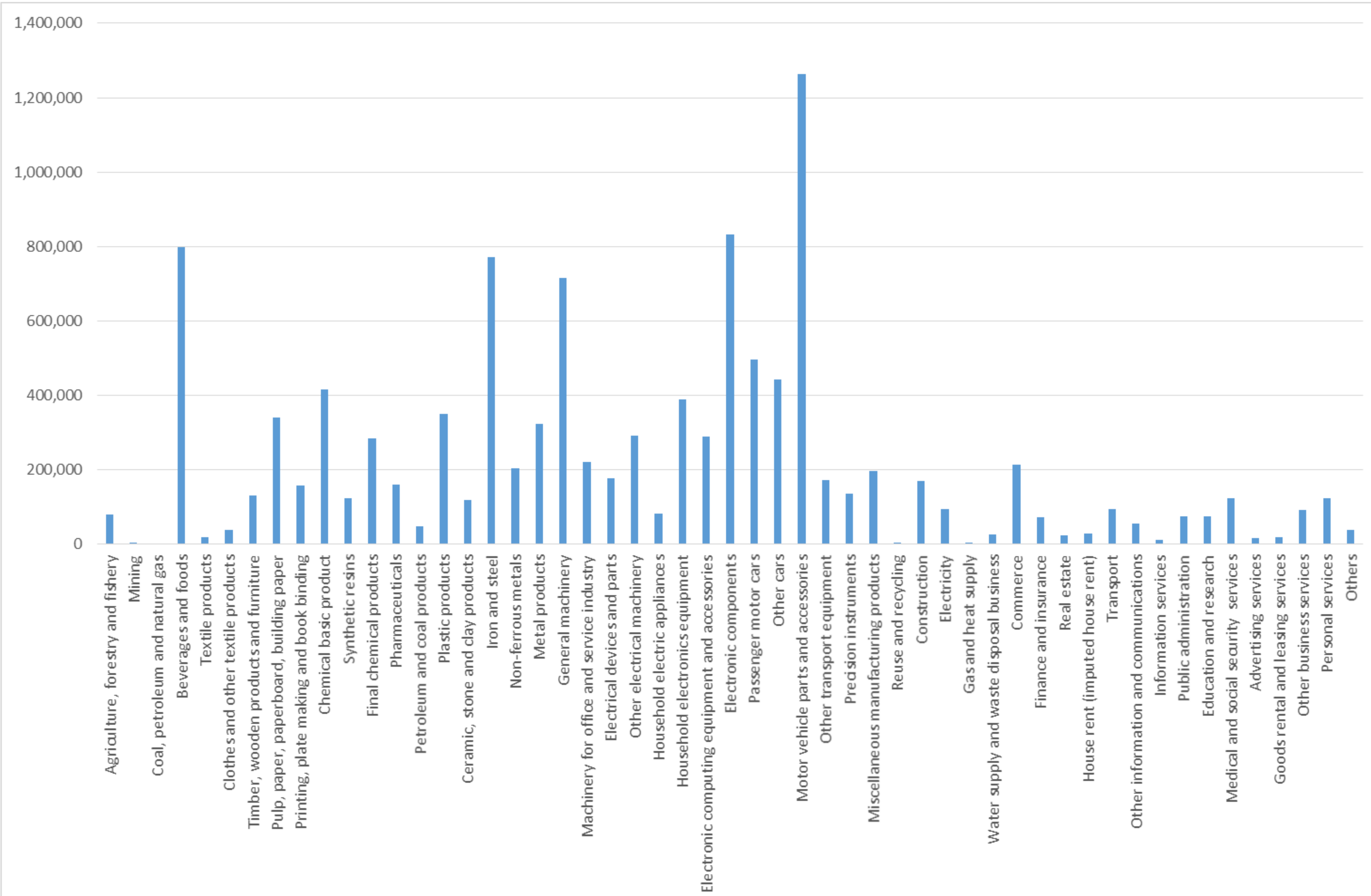

Figure 6. The total forward linkage effect by industry (non-substitutability within the Kanto region)

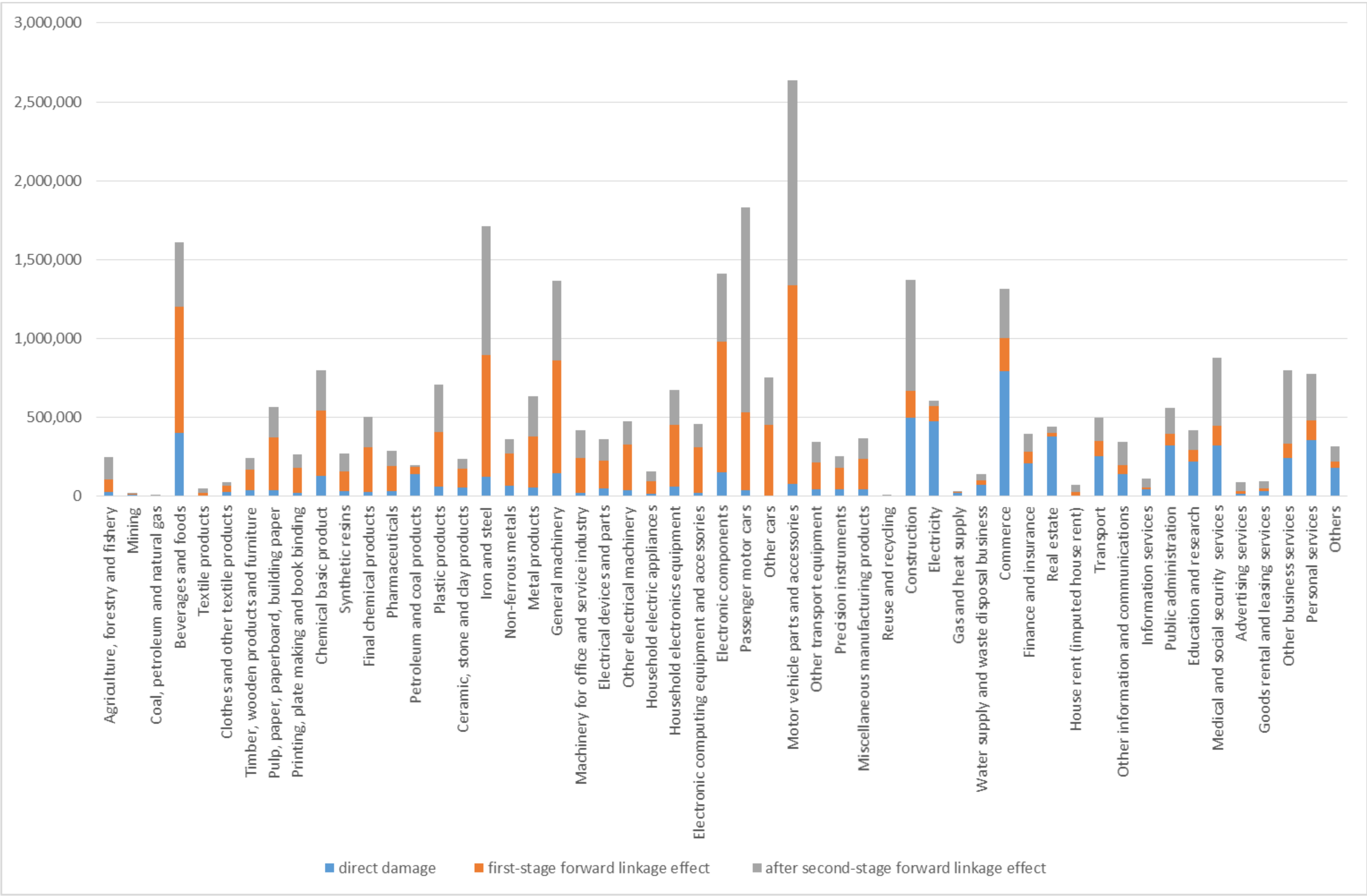

Figure 7. The first-stage forward linkage effect by industry (if there was substitutability within the Kanto region)

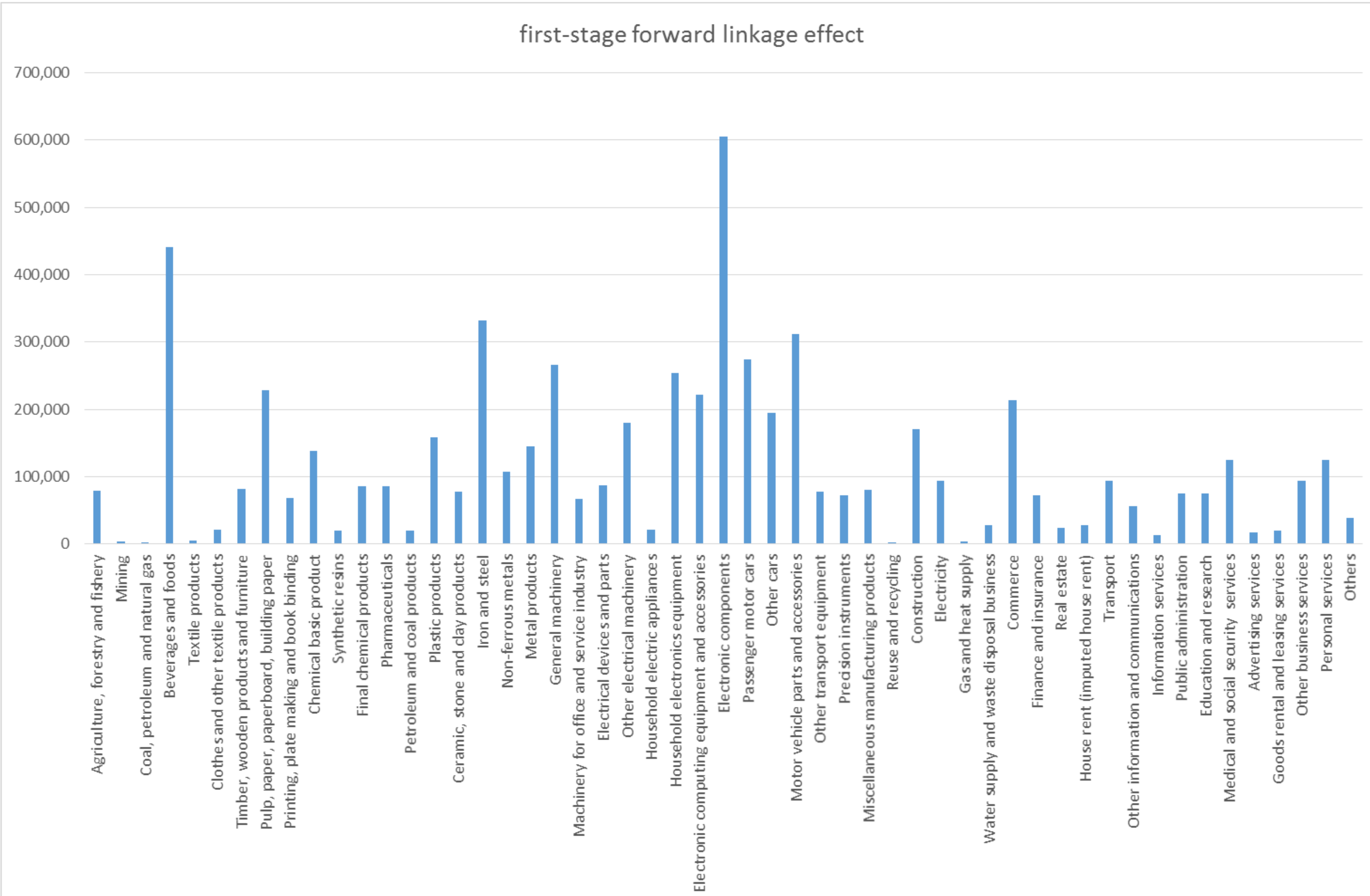

Figure 8. The total forward linkage effect by industry (if there was substitutability within the Kanto region)