Transmission of Shocks along the Global Value Chain*

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Abstract

We develop a framework of identifying impact of exogenous shocks by transmission channels and sources in the context of international input-output table. Extending the multiregional input-output models, we decompose impact from a global shock to a country into four terms: direct domestic impact, returned domestic impact, direct foreign impact, and third country impact. Two kind of shocks are of our focus. First, we analyze situation where there are changes in the global prices or production costs. Second, we investigate the changes in the global final demand. We provide a numerical example assuming a situation of abrupt increase in oil prices. Assuming ten percentage increase in global oil prices, we found that it increases price level of costs of Korean industries by about 1.77 percent when measured by World Input-Output Table in year 2010. Foreign content of the impact of oil price accounts for about 35 percent, and this share has been increasing over time which may represent the advance of the global value chain. Also, we argue that assessing the magnitude of shocks using international input-output tables can produce different results compared to the case of using single national input-output tables, since the magnitude of the shocks originating from foreign countries passed through the global value chain can also be considered as well when using the international input-output tables.

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1 Introduction

Integration of world economy has brought disintegration of production processes over various range of countries. To efficiently supply a final good, many number of firms from various locations are assigned to provide intermediate goods according to their comparative advantage and institutional situations. In turn, a final good should typically encompass primary inputs, such as, labor input, from other nation, inherited in the imported intermediate goods, which deepens interconnectedness among countries.

This situation led impact of changes in economic condition of one country to other countries more influential and widespread. Reflecting this global change, we emphasize that focal point of analyzing the impact of the global shock should be put on considering the global value chain rather than only considering domestic economic structure. In this regard, we develop a framework of identifying impact of exogenous shocks by transmission channels and sources in the context of international input-output table. Extending the multiregional input-output(MRIO) models, we decompose transmission channels of impact from a global shock to reference country into four terms: direct domestic channel, back-and-forth interaction channel, direct foreign channel, and third country channel.

Two kind of shocks are of our focus: a quantity shock caused by changes in demand condition and a price shock resulted by cost-push shock. First, we analyze the impact of changes in the global demand and quantity of each country is affected. This paper develops models that can analyze the impact of shocks that corresponds to the different types of shocks,

This paper is closely related with regional based on contributions of previous literatures on regional input-output models that are first formulated by Isard (1951).

Identifying impacts of two types of shocks under demand-pull and cost-push model is well discussed in Dietzenbacher (1997) that advocates to interpret the cost-push model as a price model, and overcome the shortcomings of using the supply-side model as pointed out by Oosterhaven (1988). We examine the possibility of consistently applying the interpretation of Dietzenbacher (1997) in our model, and provides theoretical implications of this approach in the MRIO setup.

As this paper mainly focuses on the international input-output table, it is also closely related with studies regarding global value chain. Johnson and Noguera (2012) proposes a methodology of extracting value-added component from the gross exports. Koopman, Wang, and Wei (2014), and Wang, Wei, and Zhu (2013) provides a framework of decomposing gross exports by sources of value-added and the type of goods. Hummels, Ishii, and Yi (2001) discusses a way of quantifying the relative position of a country in the vertical specialization.

2 The Model

2.1 Notations and Some Useful Expositions

Assume that we have a inter-country input-output table for $\mathbb{G} \in \{1, \cdots, G\}$ endogenous countries and $\mathbb{N} \in \{1, \cdots, N\}$ endogenous industries.[1] Endogenous countries do not necessarily compose a whole set of countries, so we consider an index, o, to represent aggregate of exogenous countries. Valuable efforts of constructing inter-country input-output tables[2] let analysis of this paper available. Given, an inter-country input-output table of certain time of interest, x_i^s which is the output of industry i[3] of country s can be expressed as,

$$x_i^s = \sum_{r=1}^{G} \sum_{j=1}^{N} z_{ij}^{sr} + \sum_{r=1}^{G} f_i^{sr} + e_i^{so}, \tag{1}$$

where z_{ij}^{sr} is the amount of output of industry i in country s absorbed in industry j of country r. f_i^{sr} is the final demand of country r for the output produced in the industry i of country s. e_i^{so} is the export of industry i of country s to exogenous countries. m_i^{osa} is the import of industry i of country s from exogenous countries. Such an exposition has been long been developed since the seminal work of Isard (1951), and this paper provides a small extension. Since we consider a case of an inter-country input-output table, x_i^{so} which represents output of industry i of country s absorbed exogenous countries constitutes the remaining part of the total output, x_i^s.

Value-added, v_i^s, for industry i of country s is the remaining of total output from intermediate goods required, given as $v_i^s = x_i^s - \sum_{r=1}^{G} \sum_{j=1}^{N} z_{ji}^{rs} - \sum_{j=1}^{N} z_{ji}^{os}$, and the corresponding value-added coefficient, $\tilde{v}_i^s$ is defined as, $\tilde{v}_i^s = v_i^s / x_i^s$. Similarly, we define a final demand coefficient, $\tilde{f}_i^s = \sum_{r=1}^{G} f_i^{sr} / x_i^s$. Vector of value-added of size $1 \times N$ of country s, v^s is defined as $v^s = (v_1^s, \cdots, v_N^s)$. Similarly, vector of final goods of country s, f^s is

[1] We follow the notation of indexing industries and countries from much of Koopman, Wang, and Wei (2014) and Wang, Wei, and Zhu (2013).

[2] Notable examples of this type of database include World Input Output Database(WIOD) project of Timmer, Dietzenbacher, Los, Stehrer, and de Vries (2015), and Asian International I-O Table of Institute of Developing Economies(IDE) of Japan External Trade Organization(JETRO).

[3] The index i can also be representing a product instead of an industry

defined as, $f^s = (\sum_{r=1}^{G} f_1^{sr}, \cdots, \sum_{r=1}^{G} f_N^{sr})'$.

Before we turn to our analysis, finding relationship between inter-country input-output table and a national input-output table provides a good exercise. For a country s, the $N \times N$ matrix $Z^{ss} = (z_1^{ss}, \cdots, z_N^{ss})$ where $N \times 1$ vector $z_i^{ss} = (z_{i1}^{ss}, \cdots, z_{iN}^{ss})'$ is the domestic intermediate goods transaction table of the non-competitive type. In this case, import transaction table can be represented as $N \times N$ matrix M^s, such as, $M^s = (m_1^s, \cdots, m_N^s)$ where $N \times 1$ vector m_i^s is $m_i^s = (m_{i1}^s, \cdots, m_{iN}^s)'$, and m_{ij}^s is import of country s from other countries, such as, $m_{ij}^s = \sum_{r \neq s} z_{ij}^{rs}$. As noted in Koopman, Wang, and Wei (2014), $N \times 1$ gross export vector of country s, e^s, can be expressed as, $e^s = (e_1^s, \cdots, e_N^s)'$, where $e_i^s = \sum_{r \neq s} \sum_{j=1}^{N} z_{ij}^{sr} + \sum_{r \neq s} f_i^{sr}$.

Hence, intermediate goods transactions table from country s to r, Z^{rs}, where i-th row and j-th column element is $Z^{rs}(ij) = z_{ij}^{rs}$, is embedded in the competitive import transactions table of country s. Global intermediate transactions table of G countries and N industries is a $NG \times NG$ matrix, where diagonal part of the matrix is the domestic transactions tables, looks as,

$$Z = \begin{pmatrix} Z^{11} & \cdots & Z^{1G} \\ \vdots & \ddots & \vdots \\ Z^{G1} & \cdots & Z^{GG} \end{pmatrix} = \begin{pmatrix} z_{11}^{11} & \cdots & z_{1N}^{11} & \cdots & z_{11}^{1G} & \cdots & z_{1N}^{1G} \\ \vdots & \ddots & \vdots & \cdots & \vdots & \ddots & \vdots \\ z_{N1}^{11} & \cdots & z_{NN}^{11} & \cdots & z_{N1}^{1G} & \cdots & z_{NN}^{1G} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ z_{11}^{G1} & \cdots & z_{1N}^{G1} & \cdots & z_{11}^{GG} & \cdots & z_{1N}^{GG} \\ \vdots & \ddots & \vdots & \cdots & \vdots & \ddots & \vdots \\ z_{N1}^{G1} & \cdots & z_{NN}^{G1} & \cdots & z_{N1}^{GG} & \cdots & z_{NN}^{GG} \end{pmatrix}. \qquad (2)$$

Technical input coefficients matrix, A^{sr}, with size of $N \times N$ denotes ratio of input from s to make a unit of output of country r, is derived by dividing each j-th row of Z^{sr} with x_j^r. Hence, i-th row and j-th column element of A^{sr} becomes $A^{sr}(i,j) = z_{ij}^{sr}/x_j^r$. Then global technical coefficients matrix, A, can be acquired by replacing Z^{sr} by A^{sr} in (2). We can also compute the global Leontief inverse matrix, L, with size of $NG \times NG$ by $L = (I_{NG} - A)^{-1}$. I is the identity matrix of size $NG \times NG$. We use the word 'global' to distinguish from it from the local Leontief inverse matrices. We should note that L^{sr} which is the partition of the global inverse L is not necessarily equal to the local Leontief inverse $(I_N - A^{sr})^{-1}$.

Put in alternative way, one can impose a situation where supply side factors drives the overall output as illustrated in Ghosh (1958). In this case, we derive the direct-output coefficients matrix, B, which can be computed by dividing the elements z_{ij}^{sr} of Z by x_i^s. Then, the global output inverse matrix G can be defined by, $G = (I_{NG} - B)^{-1}$. In this case, i-th row and j-th column element of G^{sr}, g_{ij}^{sr}, measures the total output induced to industry j of country r by increase in one unit of primary input in industry i of country r. Similar to the case a partition of global output inverse matrix G^{sr} is not necessarily equal to the local output inverse $(I_N - B^{sr})^{-1}$.

Lastly, we define the global output vector $x = (x^1, \cdots, x^s, \cdots, x^G)$ of size $NG \times 1$ where a subvector of x, x^s corresponds to the output vector of country s of size $N \times 1$.

2.2 Decomposition

Based on the notation and expositions discussed in the previous section, this section describes the decomposition strategy used throughout this paper. Analysis of this paper relies on several important assumptions. First, technology coefficients are fixed, which implies the stable supply channels within considered period of time(Isard (1951)). Second, we assume a shock to affect all of the country simultaneously. Hence our model is not suitable to analyze delayed effect or asymmetry in the first round shock[4]. Third, we also assume that we understand the type of the shock, such as a shock in primary inputs, or demand.

Figure 1 illustrates the transmission channel of a global shock in a diagram. It also represents the decomposition strategy used in this paper. Numbered as channel one, there can be a direct effect of a global shock transferred to a reference economy. We name this channel as 'domestic transmission'. Second, there can be feedback of the shock between a reference country and the other foreign countries. Once the shock is transferred to a reference country, then it can give effect to other foreign countries, which can be ultimately come back to the reference country again. Third, there can be effect that is first transferred to the foreign country and then directly affecting the reference country. Lastly, the shock absorbed by a reference country can originate from a third country which transfers the impact to other country. Third and fourth channel depicts the foreign content of the impact of a global shock.

Analyzing the transmission channel depends crucially on the type of the shock that we are interested in. We provide two kinds of shocks in this paper which are, namely, demand and supply shocks. Selection of the framework of either Leontief demand-driven model or Ghosian supply-side model depends on the type of the shock that we are interested in. If

[4]However the model can well be extended to express the asymmetry in the first round shock,

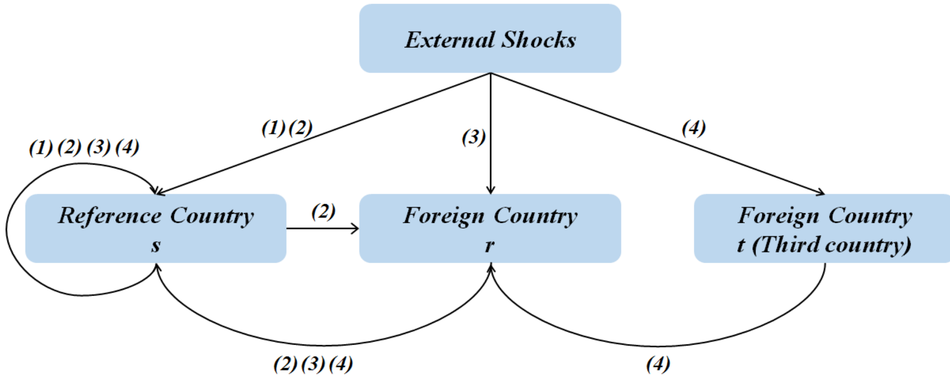

Figure 1: Decomposition of Impact by Transmission Channels

we are to analyze the demand-driven shocks, such as changes in final demand or export conditions, then it can be analyzed under Leontief demand-driven model. Supply-side shocks such as changes in primary inputs or import price changes can be analyzed under Ghosian supply-side model.

2.2.1 Decomposition in the Demand-Pull Model

Under framework of demand driven model, we assume that there are changes in the quantities and prices are fixed. That is, we would like to observe how output of reference country is influenced when the prices remain fixed.

To begin with, output of country s should satisfy following relationship by identity,

$$x^s \equiv L^{ss}\left(f^s + e^{so}\right) + \sum_{r \neq s} L^{sr}\left(f^r + e^{ro}\right), \tag{3}$$

where, e^{so} is a vector export to external sector by country s of size $N \times 1$, defined as $(e_1^{so}, \cdots, e_N^{so})$. It is clear that (3) shows relationship between output of a reference country and final demand over all regions. Alternatively, output of country s can be expressed as,

$$x^s \equiv \sum_{r \neq s} \left(I_N - A^{ss}\right)^{-1} A^{sr} x^r + \left(I_N - A^{ss}\right)^{-1}\left(f^s + e^{so}\right). \tag{4}$$

Equation (3) and (4) tells exactly the same thing. Equation (3) directly states that output of country s should satisfy amount of requirements to sustain the final demand of each region. In the other point view, we can see that output of country s should also satisfy the amount of requirements to sustain own final demand, and intermediate goods requirements from other countries. However, as intermediate goods to used from other countries are finally transmitted to sustain the global final demand as in (4), it gives exactly the same implication as (3).

Then, substituting (3) into (4), and denoting new values of final good and export to exogenous regions of country s as, f^{s*} and e^{so*}, and applying these new values gives us following relationship between new value of output, x^{s*}, and new value of final good and export to exogenous regions, such as,

$$
\begin{aligned}
x^{s*} = {} & (I_N - A^{ss})^{-1} (f^{s*} + e^{so*}) + \sum_{r \neq s} (I_N - A^{ss})^{-1} A^{sr} L^{rs} (f^{s*} + e^{so*}) \\
& + \sum_{r \neq s} (I_N - A^{ss})^{-1} A^{sr} L^{rr} (f^{r*} + e^{ro*}) \\
& + \sum_{r \neq s} (I_N - A^{ss})^{-1} A^{sr} \left[\sum_{t \neq s,r} L^{rt} \left(f^{t*} + e^{to*} \right) \right]. \qquad (5)
\end{aligned}
$$

Decomposing new output value by sources of final good demanded as in (5) has some meaningful economic interpretation. The first term of left-hand side of (5) represents amount of output of country s that is directly required to sustain the final demand and exogenous export of country s. Second term is the value of goods that are produced in country s that is required to satisfy final demand and exogenous export of country s, but needs to be first exported to other country as intermediate goods. Third term is the amount of output s that is required to sustain final demand and exogenous export of other countries. Fourth term is the amount of output of country s that is needed to sustain final demand and exogenous export of third country, and exported as intermediate goods to countries other than the third country in interest.

Hence, first and second term refer to the domestic content of the new output that sustains the new final good demand and the exports to exogenous regions. If a country is highly dependent on the final demand of other countries, then this will tend to increase third and fourth term which constitutes foreign content of new values of final goods demand and exogenous exports.

How does the result derived in the context of demand-pull model related with the supply-driven model? It is well known from Dietzenbacher (1997) that Leontief quantity model and the Ghosh quantity model gives equivalent result when we interpret the Ghosh inverse in the Ghosh quantity model as percentage increase from the original output level. We investigate if the same interpretation apply in the context of inter-country input-output table, and each transmission channels displayed in (11), and conclude that the result of Dietzenbacher (1997) can also be applied to our analysis.

It is useful to remind the relationship between local Leontief and Ghosh inverse, and show that similar arguments can be applied in global sense. Since input coefficients and output coefficients are defined as $A^{sr} = Z^{sr}(\hat{x}^r)^{-1}$, and $B^{sr} = (\hat{x}^s)^{-1} Z^{sr}$ respectively, local Leontief inverse and Ghosh inverse matrices have following relationship

$$(I_N - A^{ss})^{-1} = \hat{x}^s (I_N - B^{ss})^{-1} (\hat{x}^s)^{-1}.^5 \tag{6}$$

Similarly, global Leontief inverse and Ghosian inverse have following interesting relationship,

$$\hat{x}^s G^{sr} (\hat{x}^r)^{-1} = L^{sr}. \tag{7}$$

Then, we apply ratio of changes in values of final demand and exports as, $df^s = (\hat{f}^s)^{-1} f^{s*}$, and $de^{so} = (\hat{e}^{so})^{-1} e^{so*}$, where $\hat{f}_0^s$ and $\hat{e}_0^{so}$ is the diagonal matrix where diagonal elements are values of the final demand and export to exogenous regions. f_1^s and e_1^{so} are vectors indicating new values of final good and export to exogenous regions. Rearranging (5) by using results from (6) and (7) gives,

$$\begin{aligned}(\hat{x}^s)^{-1} x^{s*} = &(I_N - B^{ss})^{-1} (\hat{x}^s)^{-1} \left(\hat{f}^s df^s + \hat{e}^{so} de^{so}\right) \\ &+ \sum_{r \neq s} (I_N - B^{ss})^{-1} B^{sr} G^{sr} (\hat{x}^s)^{-1} \left(\hat{f}^s df^s + \hat{e}^{so} de^{so}\right) \\ &+ \sum_{r \neq s} (I_N - B^{ss})^{-1} B^{sr} G^{rr} (\hat{x}^r)^{-1} \left(\hat{f}^r df^r + \hat{e}^{ro} de^{ro}\right) \\ &+ \sum_{r \neq s} (I_N - B^{ss})^{-1} B^{sr} \left[\sum_{t \neq s,r} G^{rt} (\hat{x}^t)^{-1} \left(\hat{f}^t df^t + \hat{e}^{to} de^{to}\right) \right].\end{aligned} \tag{8}$$

Comparing (5) to (8), the relationship between the Leontief model and the Ghosh model becomes clear. The difference between two models is that Leontief model as (5) gives new output value driven by new values of final good and exogenous export, while Ghosh model gives percentage change in output by percentage changes in final good and exogenous export.

[5] Note that this relationship does not imply $(I_N - A^{sr})^{-1} = \hat{x}^s (I_N - B^{sr})^{-1} (\hat{x}^r)^{-1}$ when $s \neq r$. The relationship presented in (6) only applies when $s = r$.

2.2.2 Decomposition in the Cost-Push Model

The procedure of decomposing changes in output induced by changes in primary inputs is similar to the case of demand-pull model. In this context, we consider the case when their is change in the prices of imported goods or the primary inputs. Hence, the quantity remains fixed, so that the changes in the output are only caused by price changes. Interpreting the basic relationship in (1) as the Ghosh price model, output of our reference country s, x^s can be represented as,

$$x^s \equiv (v^s + m^{os}) G_{ss} + \sum_{r \neq s} (v^r + m^{or}) G_{rs}. \tag{9}$$

In this case, (9) states that production of country s induced by primary inputs of every country should equal to the total output of country s, such as,

$$x^s \equiv \sum_{r \neq s} x^r B^{rs} (I_N - B^{ss})^{-1} + v^s (I_N - B^{ss})^{-1} + m^s (I_N - B^{ss})^{-1}. \tag{10}$$

Alternative to expression in (9), is given as (10) which states that total output of country s equals to production directly induced by primary inputs of country s plus production induced by intermediate inputs supplied by other countries. As in the relationship between (3) and (4), we can see that (9) and (10) are only showing the alternative way of expressing output of a certain country. Denoting the new value-added and imports from exogenous countries vector of country s as v^{s*} and m^{s*} respectively, and substituting (9) into (10) gives,

$$\begin{aligned} x^{s*} = & (v^{s*} + m^{s*}) (I_N - B^{ss})^{-1} + \sum_{r \neq s} (v^{s*} + m^{s*}) G^{sr} B^{rs} (I_N - B^{ss})^{-1} \\ & + \sum_{r \neq s} (v^{r*} + m^{r*}) G^{rr} B^{rs} (I_N - B^{ss})^{-1} \\ & + \sum_{r \neq s} \left[\sum_{t \neq s,r} \left(v^{t*} + m^{t*}\right) G^{tr} \right] B^{rs} (I_N - B^{ss})^{-1}. \end{aligned} \tag{11}$$

Interpretation of (11) is straightforward. The first term in the right-hand side of (11) is the output value by changed price of domestic primary inputs, and only processed inside the domestic boundaries. The second term refers to the output induced by changed price of domestic primary inputs as the first term, but the difference is that it deals with the exported intermediate goods that are imported back to the reference country as intermediate goods to be processed at the reference country or the final goods that are directly absorbed by the households.

Other two terns in the right-hand side of (11) shows the foreign contribution to the new output value, x^{s*}. Third term in the right-hand side of (11) represents the new output value by changed price of primary input of other country, r. The last term also refers to the foreign contribution, but it represents the new output value by the changes in the primary inputs of the third country, indexed by t, that provide intermediate goods to other country, indexed by r that will be transferred to the reference country s, at last.

As in the previous case of the demand-pull model, we apply the Leontief price model to (11). Denoting denote the price ratio changes of primary inputs as, $dv^{s*} = v^{s*}\left(\hat{v}^s\right)^{-1}$, and (6) and (7) gives,

$$
\begin{aligned}
x^{s*}\left(\hat{x}^s\right)^{-1} = & \left(dv^s\hat{v}^s + dm^s\hat{m}^s\right)\left(\hat{x}^s\right)^{-1}\left(I_N - A^{ss}\right)^{-1} \\
& + \sum_{r\neq s}\left(dv^s\hat{v}^s + dm^s\hat{m}^s\right)\left(\hat{x}^s\right)^{-1} L^{sr} A^{rs}\left(I_N - A^{ss}\right)^{-1} \\
& + \sum_{r\neq s}\left(dv^r\hat{v}^r + dm^r\hat{m}^r\right)\left(\hat{x}^r\right)^{-1} L^{rr} A^{rs}\left(I_N - A^{ss}\right)^{-1} \\
& + \sum_{r\neq s}\left[\sum_{t\neq s,r}\left(dv^t\hat{v}^t + dm^t\hat{m}^t\right)\left(\hat{x}^t\right)^{-1} L^{tr}\right] A^{rs}\left(I_N - A^{ss}\right)^{-1}. \qquad (12)
\end{aligned}
$$

We can see that the result presented in (12) shows the changes in the output in ratio compared to the original output value whereas (11) shows the new output value. Post-multiplying $\left(\hat{x}^s\right)^{-1}$ to (12) would give identical results to (11)

The analysis in this section has shown a framework of decomposing transmission channels of shocks in global demand or production. If we are analyzing changes in demand conditions we should interpret such changes be in terms of quantities. Based on the Leontief quantity model, we could directly compute the new output value according to new values of final demand and exports. Using direct output coefficients of the Ghosh quantity model, we could compute the proportion of quantities change, by shock in demand as noted in Dietzenbacher (1997). In the case of supply shock, we found that Ghosh price model let us compute the new output values by changes in the prices of primary inputs, and applying Leontief price model computes proportional change in prices. Out investigation confirms that interpretation of demand-pull and cost-push model proposed by Dietzenbacher (1997) also applies in this MRIO context.

3 Numerical Exercise

This section applies the decomposition framework proposed in the previous section to two cases: reduction in global demand and the global oil price shock. First case corresponds to the case of global financial from year 2007 to 2009. Such a severe event can decrease the global demand by reducing the export to countries where crisis originated. Second case corresponds to the case of global oil price shock. We assume that shock has originated from external country, say UAE or Dubai, and it simultaneously affected other countries' price of supply sectors. We compare the result from the world input-output table with the benchmark case of domestic input-output table of Bank of Korea.[6]

3.1 Reduction of Global Demand

To be attached later.

3.2 Global Oil Price Shock

To be attached later.

4 Conclusion

Previous analysis provided a way of analyzing the impact of external global shock that simultaneously affects countries of interest. Reflecting the advance of the global value chain we develop a model that analyze the transmission channel of a shock. We consider the case of quantity shock where global demand has diminished, and also examine the case of price shock where the price of primary inputs have changed exogenously. In both cases, we compare the difference between the supply-driven and demand-pull model and conclude that the two models only differ in interpretation of outcome of the analysis in values or ratios, which also shows that the result of Dietzenbacher (1997) can also be applied to the case of multi-region input-output analysis.

[6]Numerical Exercise of other countries with domestic input-output table can be easily done by using pre-existing framework.

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