Structural Decomposition Analysis of Japan’s Energy Transitions and Related CO₂ Emissions in 2005–2015 Using a Hybrid Input-Output Table

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Abstract
This study investigates Japan’s energy transitions in 2005–2015, which involved massive economic disruptions due to the 2011 Great East Japan earthquake and the Great Recession. A hybrid input-output (IO) table that conforms to the energy conservation condition was newly compiled by integrating the Japanese energy-balance and linked-IO tables. This was employed to conduct a structural decomposition analysis (SDA), which attributes changes in energy consumption and CO₂ emissions to the effects of intensity, structure, domestic final demand, and export. These effects were successfully segregated into a profile of energy sources. The results revealed that the structural effect became the dominant driver for decisively reducing energy consumption and emissions of manufacturing and service sectors in the latter period 2011–2015. This suggested that it took time to materialize energy-saving innovations in response to the sudden economic disruptions. Over the entire period, the structural effect was the largest driver contributing to the overall reductions, in part because the other effects tended to cancel out either between energy sources or periods. Therefore, a sensible way to transform Japan to a less energy-intensive, carbon-free society in the future is to improve the non-energy input structures of the manufacturing and service sectors.

Keywords Climate change · Energy · Fossil fuel · Input-output analysis · Structural decomposition analysis

1 Introduction

1.1 Background

Energy transitions of countries have often been influenced by massive economic disruptions. During 2005–2015, Japan experienced two such events: the 2011 earthquake and the Great Recession. The Great East Japan earthquake occurred on 11th March 2011, with
a main shock of magnitude M9.0, making it one of the largest earthquakes in recorded history. The earthquake thrust tectonic plates 450 to 500 km in length off the coast of the Tohoku region in northeast Japan. A subsequent massive tsunami hit the coastal areas parallel to the plates, inundating 56,100 ha of land with water columns up to 40 m in height (Suzuki and Nakazato 2012). This massive disaster resulted in the deaths of more than 15,000 people, and more than 4000 were reported missing. The tsunami also inundated the TEPCO Fukushima Daiichi nuclear power plant, leading to a failure in cooling of the nuclear fuel a few days after the earthquake (IAEA 2015).

This disaster hit the Japanese economy hard. Immediately after the earthquake, supply chains were disrupted because many factories in the region were severely damaged, as was key infrastructure. The economic outputs of 4 prefectures in the region, namely Iwate, Miyagi, Fukushima, and Ibaraki, fell by 30–50% immediately after the earthquake (Tokunaga et al. 2017). Effects of the disaster were particularly felt in the electricity sector. Damages from the disaster resulted in the suspension of most nuclear and fossil-fuel power plants along the coast, thereby forcing much of the Tokyo Metropolitan area to implement a rotational blackout scheme for 10 days in March 2011 (ANRE 2012). During the following summer season, the power supply capacity remained insufficient, so industries and households in the Kanto (including Tokyo) and Tohoku regions were asked to reduce electricity consumption by 15% (ANRE 2012). These constraints broadly influenced economic activities in Japan (Ishikura and Ishikawa 2011).

Stricter safety regulations concerning nuclear plants introduced after the disaster eventually brought all activities at nuclear plants across the country to a halt by September 2013, and subsequent resumptions of operations have been gradual (Fig. 1) (ANRE 2020; 2021). The resultant power shortage motivated the Japanese government to promote the development of renewable energy by introducing a feed-in-tariff (FIT) scheme in July 2012, which has since encouraged rapid solar photovoltaic (PV) installations (Ueda et al. 2019). Consequently, power generation by solar PV has grown from 4 TWh in 2010 to 69 TWh (6.7%...
of the total generation) in 2019 (Fig. 1). However, the increased generation capacity from renewable energy sources has not been sufficient to cover the full capacity of nuclear plants that were in operation before the disaster. Therefore, the gap has been filled by fossil-fuel power plants (Fig. 1), whose share increased from 65 to 76% between 2010 and 2019.

Another event that significantly disrupted the national economy in the same period was the Great Recession triggered by a financial crisis in the United States in 2008. Ball (2014) found from empirical studies of 23 OECD countries that the recession brought about long-term damages that lasted until 2015 to the countries’ economies, including Japan. Possible damages involved a loss of potential outputs due to the reduction in capital accumulation, the loss of workers’ skills during unemployment, and the disruption in economic activities for producing technological progress (Ball 2014). These economy-wide impacts may have led to an eventual change in energy consumption levels and mixes. The impacts of the Great Recession on energy uses inexorably overlapped those of the Great East Japan earthquake during this period.

Significant transitions of energy sources in Japan amid those two events call for not only a simple overview of trends in energy statistics such as the ones presented in Fig. 1, but also a thorough investigation into the structural changes in energy supply and demand. One of the most useful tools for this purpose is structural decomposition analysis, which incorporates an input-output (IO) technique (simply called SDA hereafter) (e.g., Wang et al. 2017). Previously, Okuyama (2014) investigated structural change in the regional economy after the 1995 Kobe earthquake using SDA. Nevertheless, the 2011 Great East Japan earthquake was distinct from previous earthquake events in Japan because it disrupted the energy sector so extensively. Therefore, a new study is required regarding the 2011 earthquake, with a particular focus on energy sectors.

1.2 Overview of Methodologies

An SDA of energy is a technique in which overall changes in energy consumption between two periods are decomposed into various effects. There are two major approaches to an energy SDA: a monetary IO model and a hybrid IO model.

The monetary IO model employs a standard IO table expressed entirely in monetary units. It first evaluates output effects from final demand in monetary terms. They are then multiplied by energy consumption coefficients (intensity factors), which define direct energy use per unit output in each sector, to estimate total energy consumption (e.g., Su et al. 2010; Akpan et al. 2015). The model is typically formulated as:

\[
q = \hat{c}Lf
\]

\[
q' = l'q = l'\hat{c}Lf
\]

Where \( f \) is a vector of final demands; \( L \) is a standard Leontief inverse matrix in monetary units; \( \hat{c} \) is a diagonal matrix of direct-energy-consumption coefficients (intensity factors); \( q \) is a vector of sector-wise total (direct and indirect) energy consumptions in producing commodities satisfying \( f \); \( l' \) is the row vector of 1’s (i.e., a summation vector); and \( q' \) is the economy-wide total energy consumption satisfying \( f \).

The hybrid IO model, by contrast, employs a “hybrid unit” IO table in which energy transactions and outputs are expressed in physical energy units while the rest is in normal monetary units. A mathematical formulation of this model is provided in Sect. 2. This type
of model was first proposed by Bullard and Herendeen (1975), and later expanded, among other uses, to the analysis of pollution due to fuel combustion by Casler and Blair (1997). Hoekstra and van den Bergh (2002) reported in their literature review that about a third of environmental SDA studies had employed the hybrid unit method since 1972. Advantages and disadvantages of using the hybrid IO model are summarized below.

The first advantage is that expressing energy in physical units allows explicit descriptions of energy flows occurring outside of economic transactions. Hence, the hybrid IO model can explicitly and independently account for the different types of renewable energy, such as solar and wind power, which are directly harvested from nature. This advantage is shared by other sorts of physical IO tables describing waste streams or environmental pollutants (Hoekstra and van den Bergh 2002). In the monetary IO model, by contrast, any energy consumption must first be associated with an increase in monetary outputs of a certain sector (Eq. (1)). When a majority of primary energy comes from fossil fuels, which are economic commodities themselves, this does not cause much problem. However, as shares of renewable energy are likely to increase into the future, this advantage of the hybrid model will become ever more important.

Second, the hybrid IO model can evaluate energy flows in a stable physical unit, and hence estimation results are robust against changes in energy prices (Hoekstra and van den Bergh 2002). This advantage is increasingly relevant as a longer period of time is studied. Likewise, physical-unit accounting enables consistent estimations when energy prices are not uniform across energy-consuming sectors (Miller and Blair 2009). Moreover, rows of energy sectors in a hybrid IO table can be compiled in accordance with the energy conservation condition. This ensures that analytical results also conform to this condition (Miller and Blair 2009).

Third, the hybrid IO model expresses energy flows in cascades, from primary energy (e.g., crude oil and hydropower) to secondary energy (e.g., electricity and heat) and finally to non-energy (energy-consuming) sectors. This feature makes it straightforward to attribute energy consumption to each primary or secondary source of energy. This is in contrast to the monetary IO model, in which energy consumptions attributable to various sources are often lumped together, as shown in Eqs. (1) and (2).

On the other hand, the hybrid IO model also has disadvantages. First, compiling a hybrid IO table is data intensive (Hoekstra and van den Bergh 2002) – information ought to be drawn from many energy statistics, which can be tedious and require a great deal of specialized knowledge. Fortunately, the Japanese government has made available detailed energy balance tables comprising several hundred sectors (ANRE 2021). They can be incorporated into a hybrid IO table with appropriate care.

Second, whereas the hybrid IO model is robust in evaluating energy consumption or energy-related CO₂ emissions, it is not straightforward in estimating greenhouse gas (GHG) emissions that are unrelated to energy consumption (e.g., methane emissions from farmlands). Because the hybrid model simultaneously evaluates output effects of non-energy sectors in monetary units, it is still possible to multiply these by non-energy-related GHG emission coefficients (in emission/money output) to evaluate non-energy-related emissions separately from energy-related ones. But doing so is awkward and the hybrid model cannot claim any advantage over the monetary model in this respect.

Third, the hybrid IO model is not suitable for undertaking an elaborate SDA on final demand effects. The model is still capable of estimating the overall final-demand effect or final-demand distribution effects (Miller and Blair 2009), that is, contributions from segregated final-demand sectors such as domestic final demands and exports. By contrast, the hybrid model is considered inadequate for estimating the effects of changes in consumption.
mixes (baskets) or levels (Dietzenbacher and Stage 2006). Thus, the hybrid model is relatively unsuitable for examining the impacts of large economic disruptions on household behaviors.

1.3 Review of SDA Applied to Energy or CO₂ Emissions Targeting Japan

Nansai et al. (2002; 2003), among others, provided some of the most detailed and representative energy-consumption and GHG-emission coefficients for Japan. This work has since contributed to the expansion of energy and environmental SDA research targeting Japan with a monetary IO model. Such studies decomposed energy consumption and/or CO₂ emissions into various effects under different names. Here, I broadly categorize them into three effects: the energy/carbon intensity effect (a change in \( c \) in Eq. (1)), the structural effect (a change in \( L \)), and the final-demand effect (a change in \( f \)). Yabe (2004) decomposed changes in CO₂ emissions in Japan between 1985 and 1995 and found that both the carbon-intensity and structural effects contributed to an emission reduction during the late 1980s but not during the recession in the early 1990s. Gerilla et al. (2005) similarly decomposed a change in carbon emissions in the Japanese housing sector during 1980–1995 and revealed the contributions from each effect. Okamoto (2013) further segregated each effect into four segments of the economy and concluded that contributions of the transitions to a service economy were not negligible during 1990–2005. Akpan et al. (2015) investigated CO₂ emission changes in Japan in 1995–2005 and found that the final-demand and structural effects, respectively, drove changes in 1995–2000 and 2000–2005. They also performed a second-stage decomposition of the structural effect into industrial sectors. Hasegawa (2006) investigated CO₂ emissions at the prefectural level in Japan and found that the effects influencing changes in emissions differed among regions.

Furthermore, some studies looked deeper into linkages along supply chains among non-energy sectors. Oshita (2012) applied the structural path decomposition method to Japan’s CO₂ emissions in 1990–2000 and revealed significant linkages from, for example, electricity to amusement/recreation and to household demand. Morioka et al. (2018) decomposed changes in Japan’s CO₂ emissions in 1990–2005 into the effects of backward-linkage, forward-linkage, and kernel structure, and found some stable linkages, with respect to kernel structure, within the supply chains.

Looking over these studies, the monetary IO model has provided useful and elaborate insights from the viewpoint of energy consumers (i.e., both the intermediate and final demand sectors). In contrast, none of them was able to attribute energy consumption or CO₂ emissions to each energy source. One way to mitigate this problem is by using an SDA together with the hybrid IO model. Nonetheless, few studies have adopted this approach for Japan. Han and Lakshmanan (1995) compiled a hybrid IO table in 1975–1985 for Japan and conducted an SDA to decompose energy-use changes into the effects of direct energy efficiency, fuel substitutions, and changes in non-energy inputs. However, they failed to evaluate the contributions from each energy source independently. Kagawa and Inamura (2001) compiled a hybrid rectangular IO table in 1985–1990 for Japan and applied it to an energy SDA in which the causes of energy consumption changes were decomposed into the effects of energy and non-energy sectors. They also delineated the contributions from energy sources categorized into 6 broad sectors. However, their discussions failed to classify these sectors into primary and secondary energy and to explicitly treat the energy conservation condition.
1.4 Objectives of this Study

To overcome the flaws of the previous studies, this study newly attempts to integrate Japanese energy-balance and linked IO tables to compile hybrid IO tables with target years of 2005, 2011, and 2015, which cover the transition period before and after the 2011 earthquake and the Great Recession. Employing the Japanese energy balance table is advantageous because it is composed in strict accordance with the energy conservation conditions. This approach represents an advancement over that of Kagawa and Inamura (2001), who relied on Nansai’s energy coefficients and other statistics to compile their hybrid IO.

My hybrid IO table is then employed to perform an SDA of energy consumption and related CO₂ emissions. Specifically, I largely follow the methodology of Miller and Blair (2009), which in turn was built around that of Bullard and Herendeen (1975). I opted for the Miller and Blair method because it enables easier observations of physical energy flows across the economy (i.e., from primary to secondary energy sectors and non-energy sectors) conforming with the energy conservation condition. With this method, I put an emphasis on delineating the contributions from each energy source at both primary and secondary energy levels. Furthermore, I expanded the Miller and Blair method to decompose the technological effect into intensity and structural effects. As an extension to energy analysis, I also examined CO₂ emissions by fossil fuel combustion¹, because it is important to reveal how the two massive events affected Japan’s long-term goal of building a carbon-free society.

2 Methodology

2.1 Data Sources

Rows of energy sectors (the shaded sub-matrices in Fig. 2) of the hybrid IO table were compiled from the energy balance table of the comprehensive energy statistics of Japan² (ANRE 2021), which describes energy flows among sectors in physical energy units (TJ), so that the analysis conforms with the energy conservation condition. The table features 60 columns of energy carriers (18 primary and 42 secondary) and 64 rows of sectors (6 primary-energy supply, 10 energy conversion, and 48 final energy consumption) (Kainou 2012). Rows of non-energy sectors (the plain sub-matrices in Fig. 2) were compiled from the linked national IO table of Japan (called the IO table hereafter) obtained from MIC (2020). I used the linked tables for 2005, 2011, and 2015, which comprise 496 rows and 380 columns. They are evaluated in fixed prices of the base year, 2015.

I moderately aggregated the sectors listed in the above energy-balance and IO tables to the 57 sectors shown in Table 1. A foremost issue arising from this treatment is the sector aggregation problem, that is, the inevitable loss of information of sectorial details through aggregation and the ensuing possible errors in estimation results (e.g., Lenzen 2011). I certainly concur that sectorial details should be preserved as much as possible, and therefore compiled my hybrid IO table as follows. Most importantly, I preserved the

¹ On the other hand, I excluded GHG emissions unrelated to energy uses because of my focus on energy issues and the disadvantage of the hybrid IO model in dealing with them (see Sect. 1.2).
² The energy balance tables undergo occasional, retrospective updates. The tables used in this study were obtained between January and May 2020.
maximum number of energy sectors that I could retrieve from the IO table (Table 1). I did so because the energy sectors are the focus of this study, and their details are essential to the accuracy of energy and emission analyses. Likewise, I took care to preserve details of transportation sectors, which are major energy consumers. On the other hand, I moderately aggregated other non-energy sectors because the energy-balance and IO tables often have different sector definitions and resolutions for these sectors. For example, the IO table segregates agricultural produce into 31 row sectors, whereas the energy balance table lumps them together as “agriculture”. Such discrepancies in the two tables often impede detailed segregation of sectors in compiling a hybrid IO table.

Previously, Bouwmeester and Oosterhaven (2013) reported that aggregating sectors up to a 59-industry level did not produce significant errors in estimating CO$_2$ emissions and recommended that decisions about the level of sector detail should be made in consideration of the focus of the specific study. Similarly, Su et al. (2010) contended that about 40 sectors would be sufficient to analyze countries’ emissions embodied in exports. Following these arguments, I considered that the sector profile presented in Table 1 was appropriate for the purposes of this study.

A second issue regarding my choice of data sources was choosing between a single-region IO table and an international multi-regional IO (MRIO) table. This study chose to compile a single-region hybrid IO table for Japan in a competitive-import form. This treatment implies that domestic demands include both domestic and imported energy and commodities. Estimating energy consumption and CO$_2$ emissions under this setting therefore follows the domestic technology assumption (Bouwmeester and Oosterhaven

| Destination sectors | Intermediate demands | Final demands | Total output |
|----------------------|----------------------|---------------|--------------|
| Primary energy (No.1-7) | $Z^{11}$ | $Z^{12}$ | $Z^{13}$ | $y^{11}$ | $y^{12}$ | $y^{13}$ | $x^1$ |
| Secondary energy (No.8-21) | $Z^{21}$ | $Z^{22}$ | $Z^{23}$ | $y^{21}$ | $y^{22}$ | $y^{23}$ | $x^2$ |
| Non-energy (No.22-57) | $Z^{31}$ | $Z^{32}$ | $Z^{33}$ | $y^{31}$ | $y^{32}$ | $y^{33}$ | $x^3$ |
| Value-added | $V^1$ | $V^2$ | $V^3$ | |
| Total output | $x^1$ | $x^2$ | $x^3$ | |

Fig. 2 Schematic diagram of the hybrid IO table. *Note* Elements in the shaded boxes are expressed in energy units (TJ) while the rest are in monetary units (million yen)
Table 1  Sectors of the hybrid IO table

| No. | Agg. sector code | Sectors                        | No. | Agg. sector code | Sectors                                      |
|-----|------------------|--------------------------------|-----|------------------|----------------------------------------------|
| 1   | 1                | Coal                           | 28  | 10               | Pulp, paper and wood products                |
| 2   | 1                | Crude oil                       | 29  | 7                | Chemical products                            |
| 3   | 1                | Natural gas                     | 30  | 7                | Plastic products                             |
| 4   | 1                | Nuclear                         | 31  | 6                | Ceramic, stone and clay products             |
| 5   | 1                | Hydropower                      | 32  | 8                | Iron and steel                               |
| 6   | 1                | Other renewables                | 33  | 8                | Non-ferrous metals                           |
| 7   | 1                | Recoveries of wasted energy     | 34  | 8                | Metal products                               |
|     |                  | *Primary energy*                | 35  | 9                | General machinery and precision instruments  |
|     |                  | *Secondary energy*              | 36  | 9                | Electrical machinery                         |
| 8   | 1                | Coal products                   | 37  | 9                | Information and tele-communication devices   |
| 9   | 1                | Gasoline                        | 38  | 9                | Electronic parts                             |
| 10  | 1                | Jet fuel oil                    | 39  | 9                | Transport equipment                          |
| 11  | 1                | Kerosene                        | 40  | 10               | Miscellaneous manufacturing products         |
| 12  | 1                | Diesel oil                      | 41  | 11               | Construction                                 |
| 13  | 1                | Heavy oil A                     | 42  | 11               | Water supply and waste disposal              |
| 14  | 1                | Heavy oil BandC                 | 43  | 12               | Commerce                                     |
| 15  | 1                | Naphtha                         | 44  | 12               | Finance and insurance                        |
| 16  | 1                | Liquified petroleum gas         | 45  | 12               | Real estate                                  |
| 17  | 1                | Other oil products              | 46  | 13               | Railway transportation                       |
| 18  | 1                | City gas                        | 47  | 13               | Road transportation                          |
| 19  | 2                | Electricity (excluding 20)      | 48  | 13               | Water transportation                         |
| 20  | 3                | In-house (auto) power generation| 49  | 13               | Air transportation                           |
| 21  | 4                | Heat generation                 | 50  | 13               | Other transportation services                |
|     |                  | *Non-energy commodities*        | 51  | 12               | Information and communications               |
| 22  | 5                | Agriculture                     | 52  | 12               | Public administration                        |
| 23  | 5                | Forestry                        | 53  | 12               | Education and research                       |
| 24  | 5                | Fishery                         | 54  | 12               | Medical service, health, social security and nursing care |
Table 1 (continued)

| No. | Agg. sector code | Sectors             | No. | Agg. sector code | Sectors            |
|-----|------------------|---------------------|-----|------------------|--------------------|
| 25  | 6                | Mining              | 55  | 12               | Business services and NPOs |
| 26  | 10               | Food and beverage   | 56  | 12               | Personal services  |
| 27  | 10               | Textile products    | 57  | 12               | Others             |

*Note* The “Agg. sector code” indicates the corresponding 13 aggregated sectors in Table 3 (see Appendix)
2013); that is, input structures and energy intensities in foreign countries are equivalent to those in Japan. Thus, it inevitably creates specification errors when technologies differ among countries. Overcoming this issue ideally calls for using an international MRIO table and the associated environmental coefficients, such as those found in the GTAP database (Peters et al. 2011). However, resolutions of energy sectors for available MRIO tables are less than those of the Japanese IO tables and are therefore insufficient for the purposes of this study. In addition, it is beyond my current capacity to construct a global MRIO table in a hybrid format that features sufficient energy-sector resolution and is consistent with the energy conservation condition. Therefore, I opted to construct a single-region hybrid IO table for Japan and leave the remaining issues to be addressed in future studies.

2.2 Compilation of the Hybrid IO Table

I constructed a hybrid IO table comprising 21 energy sectors (7 primary and 14 secondary) and 36 non-energy sectors (Table 1). The intermediate transactions between these sectors, as well as final demands and value-added, were compiled in a competitive-import format (Fig. 2). The table evaluates energy transactions and outputs in energy units (terajoule, TJ), while the other inputs/outputs are in monetary units (million yen). Compilation methods for the table are described in Supplementary Material B. Compliance with the energy conservation condition was an important consideration; Sections SC.1 to SC.3 of Supplementary Material C discuss how this was theorized and empirically tested.

2.3 IO model for Energy Analysis

The analytical methodologies follow, and partly expand upon, the method of Miller and Blair (2009). By extracting information from the hybrid IO table, energy flows among the sectors can be summarized in a matrix:

\[ \alpha x = \alpha Z + G \]  

(3)

Where \( \alpha = [\alpha_{ki}] \) is a matrix indicating the total energy requirement of type \( k \) in producing a unit output of sector \( i \) \((m \times n)\); \( \hat{x} \) is a diagonal matrix of the total outputs \((n \times n)\); \( Z \) is a matrix of intermediate inputs \((n \times n)\); \( G \) is a matrix of the primary energy inputs \((m \times n)\), whose diagonal elements \( g_{ii} \) \((i = 1 \text{ to } m)\) are the primary energy input into the \( i \)th energy sector, with the other elements being zeros; and \( m \) and \( n \) indicate the numbers of energy sectors (21) and all sectors (57), respectively.

The left-hand side of Eq. (3) indicates the total energy requirement of type \( k \) in producing output \( x \) of sector \( j \). On the right-hand side, \( \alpha Z = [\alpha_{ki}] [z_{ij}] \) indicates all of the necessary energy inputs of type \( k \) to drive the production process of sector \( j \); and \( G \) is the primary energy inputs extracted from the ground.

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3 For instance, the GTAP has 3 primary (coal, oil, and gas) and 3 secondary (petroleum/coal products, electricity, and gas manufacture) energy sectors (Aguiar et al. 2016), while the WIOD Project (Dietzenbacher et al. 2013) has 1 primary (mining) and 2 secondary (coke/refined petroleum and electricity/gas/steam) sectors.

4 Miller and Blair (2009) used matrix notations with asterisks to distinguish hybrid IO tables, but I have omitted them for simplicity.
Equation (3) is then modified as follows to obtain Eq. (4):

\[ \alpha \hat{x} = \alpha Z(\hat{x})^{-1}(\hat{x}) + G \]

\[ = \alpha A(\hat{x}) + G \]

\[ \alpha (I - A)\hat{x} = G \]

\[ \alpha = G(\hat{x})^{-1}(I - A)^{-1} \]

\[ \alpha = G(\hat{x})^{-1}L \] (4)

Where \( A = Z(\hat{x})^{-1} \) is the input coefficient matrix \((n \times n)\) and \( L = (I - A)^{-1} \) is the Leontief inverse matrix \((n \times n)\), both of which are expressed in hybrid units.

Thus, a change in \( \alpha \) expresses a change in technologies of the economy in the SDA discussed later. However, this setting does not allow a further decomposition of \( \alpha \) into the intensity (own sector) effects caused by a change in direct energy consumption by each sector, and the structural (indirect) effects due to a change in non-energy inputs of sectors. Therefore, I incorporated a new method modified after Kagawa and Inamura (2001), who similarly distinguished the effects of energy and non-energy sectors. Here, I modify \( Z \) to extract a sub-matrix \( Z^e \) expressing only energy inputs of sectors:

\[ Z^e = \begin{pmatrix} Z_{11} & Z_{12} & Z_{13} \\ Z_{21} & Z_{22} & Z_{23} \\ 0 & 0 & 0 \end{pmatrix} \] (5)

Where the definitions of sub-matrices follow those of Fig. 2.

\( Z^e \) can then be substituted into Eq. (3) and similar modifications can be performed to obtain a matrix expressing total energy consumptions initiated by direct energy uses of sectors, \( \alpha^e \):

\[ \alpha^e = G(\hat{x})^{-1}L^e \] (6)

Where \( L^e \) is a Leontief inverse matrix derived from \( Z^e \).

Note that \( \alpha^e \) traces back direct energy uses of sectors to each source via backward-linkage effects. For instance, a use of electricity can in part be traced to natural gas and evaluated accordingly. This tracing procedure counts only energy inputs at every stage of the supply chain by Eqs. (5) and (6).

A matrix expressing the total energy consumptions induced by the uses of non-energy direct inputs, \( \alpha^{ne} \), can then be obtained by the differentials between \( \alpha \) and \( \alpha^e \):

\[ \alpha^{ne} = \alpha - \alpha^e \] (7)

2.4 IO model for CO₂Emissions

This study confined analyses to CO₂ emissions due to the combustion of fossil fuels. Because CO₂ is emitted upon combustion, we need to be careful not to double count
emissions as fossil fuels change hands from primary to secondary energy and to the non-energy sectors. Section SC.4 of Supplementary Material C provides further details on this process.

First, I evaluated CO₂ emissions resulting from the direct uses of fossil fuel type \( i \) in producing a unit product of sector \( j \) by:

\[
E^d = \hat{c} \hat{A}
\]

(8)

Where \( E^d \) is the matrix of direct unit CO₂ emissions \((m \times n)\); \( \hat{c} \) is the diagonal matrix of CO₂ emission coefficients \((m \times m)\) \((t\text{-}CO₂/TJ)\), where non-fossil primary (Sectors 4–7) and secondary (Sectors 19–21) energy sectors are set to zero; and \( \hat{A} \) is the modified input coefficient matrix comprising rows of energy sectors and columns of all sectors \((m \times n)\), defined in Fig. S3b of Supplementary Material C.

Second, total CO₂ emissions from energy type \( i \) in producing a unit product of sector \( j \), \( E' \), can be expressed by the sum of indirect emissions in producing inputs to sector \( j \) and the direct emission by sector \( j \) itself, as follows:

\[
E' = E'A + E^d
\]

(9)

Where \( E' \) is a matrix of total unit CO₂ emissions \((m \times n)\).

Finally, Eq. (9) can be modified to evaluate total unit CO₂ emissions as:

\[
E'(I - A) = E^d
\]

\[
E' = E^d(I - A)^{-1} = E^dL
\]

(10)

### 2.5 Structural Decomposition Analysis (SDA)

#### 2.5.1 SDA of Energy Consumption

Total energy consumptions for producing energy and commodities that satisfy final demands are expressed as:

\[
q = \alpha f
\]

(11)

Where \( q \) is a vector of total energy consumptions\(^5\) \((m \times 1)\) and \( f \) is a vector of final demands expressed in hybrid units \((n \times 1)\).

\( \alpha \) is further segregated into contributions from energy and non-energy inputs, and \( f \) into domestic final demands and exports as:

\[
q = (\alpha^e + \alpha^{ne})(f^d + f^e)
\]

(12)

Where \( f^d \) and \( f^e \) are vectors of domestic final demands and exports, respectively, expressed in hybrid units \((n \times 1)\).

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\(^5\) Note that induced energy consumptions \( q \) comprises energy uses due to the production of both domestic and imported energy and commodities because I employed a competitive-import IO table and the exogenous-import IO model.
Hence, a change in \( q \) can be decomposed into the four effects: energy intensity (or intensity for short) \( \Delta \alpha^e \), structure \( \Delta \alpha^{ne} \), domestic final demand \( \Delta f^d \), and export \( \Delta f^e \), as follows.

\[
\Delta q = \left[ \Delta \alpha^e + \Delta \alpha^{ne} \right] 1/2(f_0 + f_1) + 1/2(\alpha_0 + \alpha_1) \left[ \Delta f^d + \Delta f^e \right]
\]

Where the subscripts indicate years 0 and 1.

Note that the above “energy intensity” effect is different from normal usages of the term in previous studies\(^6\) in that I trace direct energy uses back to sources (see Eq. (6)).

Furthermore, \( \Delta \alpha^e \) and \( \Delta \alpha^{ne} \) are segregated into each industrial sector:

\[
\Delta q = \left[ \Delta \alpha^{e(1)} + \Delta \alpha^{e(2)} + \cdots + \Delta \alpha^{e(n)} \right] 1/2(f_0 + f_1)
\]

\[
+ \left[ \Delta \alpha^{ne(1)} + \Delta \alpha^{ne(2)} + \cdots + \Delta \alpha^{ne(n)} \right] 1/2(f_0 + f_1)
\]

\[+1/2(\alpha_0 + \alpha_1) \left[ \Delta f^d + \Delta f^e \right]
\]

where \( \Delta \alpha^{(j)} = \begin{bmatrix}
0 & \cdots & \Delta \alpha_{ij} & \cdots & 0 \\
0 & \cdots & \Delta \alpha_{mj} & \cdots & 0
\end{bmatrix} (j = 1 \text{ to } n) \) expresses a change in the intensity or structural effects in sector \( j \).

Note that Eqs. (13) and (14) employ average weights in deriving SDA equations. Although I am aware that the choice among various weighting factors (e.g., Laspeyres and Paasche indices) in formulating SDA equations has been intensively discussed (e.g., Rose and Casler 1996; Su and Ang 2012a), this study does not look deeper into this issue because the use of simple average weight is often considered an acceptable choice (Dietzenbacher and Los 1998; Akpan et al. 2015).

2.5.2 SDA of CO2 Emissions

Total CO2 emissions from producing energy and commodities to satisfy final demands \( f \) are expressed by:

\[
e = E^d f = E^d L(f^d + f^e)
\]

Where \( e \) is a vector of total CO2 emissions (\( m \times 1 \)).

Accordingly, a change in total CO2 emissions, \( \Delta e \), can be decomposed into the carbon intensity (or intensity for short) effect (due to a change in emissions by direct energy uses), \( \Delta E^d \); the structural effect (due to a change in technological structures of

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\( \text{“Energy intensity” has been used in different contexts in previous studies. Miller and Blair (2009), among others, used it to mean the total energy requirement (} \alpha \text{), while many monetary IO models (e.g., Proops 1984) used it to indicate direct energy-consumption coefficients (} \hat{c} \text{), in which direct energy uses were not traced back to sources.} \)
the economy affecting indirect emissions), $\Delta L$; and the effects of changes in domestic final demands and exports, $\Delta f^d$ and $\Delta f^e$:

$$\Delta e = \Delta E^d 1/2(L_0 f_0 + L_1 f_1) + 1/2 (E^d_0 \Delta L^0 f_0 + E^d_1 \Delta L^0 f_1) + 1/2 (E^d_0 L_0 + E^d_1 L_1) [\Delta f^d + \Delta f^e]$$

(16)

Furthermore, $\Delta E^d$ and $\Delta L$ can be segregated into each sector:

$$\Delta e = [\Delta E^{d(1)} + \Delta E^{d(2)} + \ldots + \Delta E^{d(n)}] 1/2 (L_0 f_0 + L_1 f_1)$$

$$+ 1/2 E^d_0 [\Delta L^{(1)} + \Delta L^{(2)} + \ldots + \Delta L^{(n)}] f_0 + 1/2 E^d_1 [\Delta L^{(1)} + \Delta L^{(2)} + \ldots + \Delta L^{(n)}] f_1$$

$$+ 1/2 (E^d_0 L_0 + E^d_1 L_1) [\Delta f^d + \Delta f^e]$$

(17)

Where the usage of superscripts in parentheses follows those in Eq. (14).
3 Results and Discussion

3.1 SDA of Energy Consumption

Figures 3 and 4 show the results of the SDA on changes in primary and secondary energy consumptions, respectively, in 2005–2011 and 2011–2015, as well as in the combined period of 2005–2015. For showing the results of sectorial decompositions by Eq. (14), I consolidated the contributions from the 57 sectors of Table 1 into the 13 sectors of Table 3 for concise presentations in Tables 4 and 5 (intensity effect) and 6 and 7 (structural effect). (See the Appendix for Tables 3 through 11. Tables 4 to 7 summarize the results separately for the periods 2005–2011 and 2011–2015 (Tables 5 and 7). In Fig. 4 and Tables 4 to 7, energy supplies by secondary carriers are evaluated in terms of their primary energy equivalent, that is, the embodied primary energy in each secondary carrier. In this way, I avoided double counting the energy consumptions of secondary carriers. See Supplementary Material C for further discussion of this issue.

The results for the first period 2005–2011 (Figs. 3 and 4 and Tables 4, 6) partly reflect the abrupt disruption in energy supplies and the wider economy occurring in 2011 after the earthquake, as well as the economic slump caused by the Great Recession since 2008. The effects of the domestic final demand change on primary energy uses were mostly negative, with the largest decline in crude oil, followed by coal and natural gas (Fig. 3). In terms of secondary energy, declines were observed in most fossil fuels and electricity (Fig. 4).
These trends can be partly explained by stagnant economic activity\(^7\) during the period (IEEJ 2020). By contrast, an increase was observed in export effects (626 PJ by primary energy (Fig. 3)). This can be attributed in part to an increase in direct exports of coal and oil products (99 PJ) (see Supplementary Material A) and to the production of exported commodities.

The intensity and structural effects on primary energy uses clearly indicate a significant shift in energy mixes from crude oil and nuclear energy to natural gas (Fig. 3). The shift from crude oil to natural gas largely occurred before the earthquake, from 2005 to 2010, perhaps reflecting a surge in oil prices (Fig. 5), whereas nuclear energy showed a sudden decline after the earthquake in 2011, adding to the shift to natural gas (IEEJ 2020). Looking deeper into the electricity sector, a shift in energy inputs was revealed by the intensity effect (see column 2 of Table 4) rather than the structural effect (Table 6). Column 2 in Table 4 clearly indicates that the increase in fossil fuels (456 PJ in total) greatly exceeded the decrease in nuclear energy (217 PJ). This can be attributed to the energy conversion loss at fossil-fuel power plants discussed in Section SB.1 of Supplementary Material B\(^8\). In sum, this shift in energy mix augmented the intensity effect of the electricity sector (Fig. 4).

Non-energy sectors followed a largely similar trend, in which the declines in crude oil and nuclear energy were compensated by increases in coal and natural gas (Tables 4 and 6). Here, the change can be attributed to both the intensity (Table 4) and structural (Table 6) effects. In terms of secondary energy, increases in city gas, electricity, and in-house power

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7 In this period, Japan’s gross domestic product grew at an annualized average of 0.08% per year; in the latter period 2011–2015, the rate was at 1.12% per year.

8 In fact, the energy input/output ratio of the electricity sector (i.e., \(G(\hat{\chi})^{-1}\) in Eq. (4)) increased from 1.707 to 2005 to 1.846 in 2011 (and to 1.889 in 2015).
across most industries were noticeable, which suggests struggles for industries to find alternative sources of energy amid price surges in oil products.

Next, we turn an attention to the latter period 2011–2015. This period was marked by increases in the final-demand (both domestic and export) effects (Figs. 3 and 4), which may reflect an overall recovery of economic activities (IEEJ 2020). This is in contrast with general declines in the intensity and structural effects with respect to most energy carriers. In particular, declines in crude oil (Fig. 3) as well as in heavy oils and electricity (Fig. 4) were significant. By contrast, the advancement of other renewables (mainly solar PV), though at a much smaller scale, was noticeable (113 PJ in total) (Tables 5 and 7), reflecting the cumulative effect of the FIT scheme implemented in 2012.

Focusing on the intensity effect of the electricity sector (column 2 of Table 5), an additional shift in the energy mix occurred from crude oil and nuclear energy to coal and natural gas during this period. In particular, a shift to coal, which did not occur in 2005–2011, was noticeable. This can partly be attributed to declining costs for coal (Fig. 5). Looking at the non-energy sectors, general declines in the intensity and structural effects were observed irrespective of energy carrier types, with larger contributions from the structural effect (Table 7 than the intensity effect (Table 5). In particular, the decreases in electricity across the non-energy sectors were in contrast to the increases observed in the previous period 2005–2011. All of these trends imply the gradual dissemination of energy-saving technologies across industries, which were especially manifested in non-energy input structures (Table 7) in response to higher prices in most fossil-fuel markets (Fig. 5) and constraints in electricity supply after the earthquake.

Finally, looking over the entire period of 2005–2015, changes in primary energy uses were dominated by a technological shift (both in intensity and structure) from crude oil and nuclear energy to natural gas (Fig. 3). This was followed by a decline in the domestic final-demand effect on crude oil and counteracting increases in the export effects across several carriers (Fig. 3). Other comparatively minor changes were technology-induced increases in coal and other renewables. In terms of secondary carriers, the period was marked by declines in most fossil fuels, particularly heavy oils, in contrast to increases in city gas and inhouse power (Fig. 4). This partly reflected a gradual moving away from expensive types of fossil fuels. Taken together, the total trend was a decisive reduction in the structural effects, while the domestic final-demand and export effects largely cancelled each other out (Figs. 3 and 4). If we focus only on Japan’s domestic demands and hence exclude the export effect, the remaining three effects (intensity, structure, and domestic final demand) constituted a total net reduction (2,190 PJ) in primary energy uses (Fig. 3) amounting to about 11% of Japan’s total domestic primary-energy consumption in 2005. This suggests that Japan was moving towards a less energy-intensive economy during this period.

### 3.2 SDA of CO₂ Emissions

Figure 6 shows the changes in CO₂ emissions by fossil fuel combustion. For each period, they are decomposed into four effects: carbon intensity, structure, domestic final demand, and export. (Tables 8 to 11) show further sectorial decompositions of the intensity and structural effects, in 2005–2011 (Tables 8 and 10) and 2011–2015 (Tables 9 and 11). In these figures and tables, only fossil fuels are listed as energy carriers, while fossil-fuel-consuming secondary energy sectors (i.e., electricity, inhouse power, and heat) are respectively indicated in columns 2, 3, and 4 of (Tables 8 to 11). Double counting
among the primary and secondary carriers was avoided, as described in Section SC.4 of Supplementary Material C.

Similar to energy consumption, the first period 2005–2011 was marked with large declines in domestic final-demand effects, although they were partly offset by increases in export effects (Fig. 6). Increases in the intensity effects were concentrated in the electricity sector (about 79 million t-CO$_2$) (Table 8). This was clearly caused by the increases in fossil-fuel inputs, including crude oil, natural gas, and heavy oil, compensating for the decline in low-carbon nuclear energy. In the meantime, the non-energy sectors showed general declines in the intensity effects (Table 8) and irregular increases and decreases in structural effects (Table 10). Overall, the intensity and structural effects together contributed to a net increase in the total CO$_2$ emission (Fig. 6).

The latter period 2011–2015 showed a large increase in domestic final-demand effects (Fig. 6), which again followed trends in energy uses. However, it is notable that this was counterbalanced by a large reduction in the structural effect. The sectorial decomposition (Table 11) revealed that this reduction was concentrated in manufacturing (as opposed to materials) industries and service sectors (i.e., columns 9 to 12), while spreading over most rows of energy carriers. This implies modifications to the non-energy input structures of the manufacturing and service sectors contributed to the reductions because simply swapping energy sources may not produce such concurrent reductions across energy carriers. Interestingly, the large reduction due to the structural effects was deferred to this period, rather than in the previous period. This suggests that it took time for industries to implement modifications to non-energy input structures in response to the earthquake and the Great Recession. As for the intensity effect, coal showed the largest increase (Fig. 6), which was again concentrated in the electricity sector.
sector (Table 9), although this was largely cancelled out by reductions in heavy oils and other fuels in various sectors.

Looking over the whole period 2005–2015, the large total reduction in structural effects was the most significant change (Fig. 6). This was clearly a result of the consistent reductions that occurred across manufacturing and service sectors during 2011–2015 (Table 11). It is noteworthy that such an accumulation of small, diffused reductions across sectors produced such a decisive negative emission trend. Regarding the intensity effect, rapid shifts in energy mixes resulted in both upward and downward changes in emissions among energy carriers, which partly cancelled each other out (Fig. 6). However, the residual net increase in the total intensity effect (Fig. 6) should mainly be attributed to the consistent increases in the electricity sector over the entire period (Tables 8 and 9) as discussed above. Meanwhile, the domestic final-demand effect tended to swing back and forth, depending on the economic conditions in each period; these changes again cancelled each other out (Fig. 6).

### 3.3 Comparison with Previous Studies

The energy SDA of this study made it possible to systematically attribute the effects that caused energy shifts to each primary or secondary energy source while conforming with energy conservation conditions. Figures 3 and 4 show these attributions as separate profiles of primary and secondary energies, respectively. This represents an improvement on Kagawa and Inamura (2001), in which energy sectors were discussed without being categorized into primary and secondary energies. The CO$_2$ emission SDA of this study was also successful in attributing each effect to a profile of fossil fuels (Fig. 6), while contributions from the fossil-fuel-consuming sectors (electricity, inhouse power, and heat) were treated separately in the columns of Tables 8 to 11. Such attributions are in contrast to previous studies employing the monetary IO model (see Sect. 1.3), in which changes in CO$_2$ emissions due to various energy sources were often lumped together.

This study used fundamentally different methodologies, data sources, and study periods from previous studies employing the monetary IO model. Nevertheless, here I roughly compare overall magnitudes of various effects estimated by CO$_2$ emission SDAs targeting Japan. I selected three studies comprising a continuous period of 1985 through 2015 for the comparison: Yabe (2004) for the period 1985–1995; Akpan et al. (2015) for 1995–2005; and this study for 2005–2015. Table 2 shows the contributions from the three effects

| References      | Periods       | Carbon intensity | Structure | Final demand |
|-----------------|---------------|------------------|-----------|--------------|
| Yabe (2004)     | 1985-1990     | −35025           | −40366    | 200607       |
|                 | 1990-1995     | 15456            | 7677      | 40803        |
| Akpan et al. (2015) | 1995-2000     | 30995            | −90071    | 64291        |
|                 | 2000-2005     | −8851            | 125322    | −93434       |
| This study      | 2005-2011     | 41215            | 21333     | −35837       |
|                 | 2011-2015     | 3860             | −80228    | 56984        |

Unit: thousand tons of CO$_2$. *Note* Final-demand effects of Yabe (2004) are differentials between the total change and the sum of the other two effects.
(carbon intensity, structure, and final demand) to changes in Japan’s national \( \text{CO}_2 \) emissions. Looking over the whole period (1985–2015), the final-demand effects were highly positive in 1985–1990, while they were negative from 2000 to 2011. This appeared to reflect fluctuations in economic growth of the Japanese economy during the same period. The other two effects were more difficult to interpret but were generally within a similar range during the whole period.

I also compared energy and carbon intensities estimated in this study and those estimated by the 3EID method of Nansai et al. (2002) (see Supplementary Material D for a more detailed discussion). In addition to the fundamental differences in model structures (i.e., a hybrid vs. monetary approach) between the two methods, this study excluded non-energy-related \( \text{CO}_2 \) emissions such as waste incineration and limestone processing, whereas Nansai et al. (2002) included them. This methodological distinction is clearly reflected in discrepancies between the relative energy and carbon intensities of the two studies (Fig. S5 of Supplementary Material D).

4 Conclusions

This study investigated changes in energy consumption and related \( \text{CO}_2 \) emissions over the period of 2005–2015, using SDA with a hybrid IO table. A unique and foremost contribution of the study is the attribution of various effects to each primary and secondary energy source while conforming with the energy conservation condition, which was made possible by use of the hybrid IO model. For example, I revealed dominant technological (intensity and structural) shifts in the energy mix from crude oil and nuclear energy to natural gas. These findings are more comprehensive than simple observations of energy statistics or the findings of most studies that employed a monetary IO model, because this study was successful in systematically linking energy consumptions and sources through the backward linkage effects of the IO model.

Furthermore, both energy and emission SDAs reveal that the intensity and domestic final-demand effects were mainly responsible for changes in the first period 2005–2011, whereas the structural effect became the dominant driver for decisively reducing energy consumption and emissions in the second period 2011–2015, particularly in the manufacturing and service sectors. These results suggest that immediate response of industries to the sudden economic disruptions that occurred in 2005–2011 (the earthquake and the Great Recession) was to swap energy sources (i.e., the intensity effect), whereas energy-saving innovations culminating in changes in non-energy input structure (i.e., the structural effect) took time to materialize, resulting in a deferral of structural effects to 2011–2015. Looking over the entire period from 2005 to 2015, the structural effect was the most significant contributor to overall reductions in energy consumption and emissions, in part because the other effects tended to cancel each other out either between energy sources or periods.

These results have several policy implications. First, to attain significant reductions in energy consumption and \( \text{CO}_2 \) emissions across the economy, it is important to accumulate small improvements in the input structures of manufacturing and service sectors to transform them into less carbon-intensive enterprises. Second, bold shifts in energy sources among fossil fuels by big energy consumers such as electricity, as well as fluctuating performances in the national economy, sometimes bring about large changes in energy use and \( \text{CO}_2 \) emissions in each energy carrier or over periods of time. However, they tend to cancel each other out, and hence, their net contribution to establishing
a carbon-free society over a longer term may be disappointingly small. Therefore, it is wise not to expect large contributions from the simple swapping of energy carriers among fossil fuels or from stagnant economic conditions. Instead, shifts in energy mixes should be steered firmly toward low-carbon energy sources, such as renewables, to materialize a long-term reduction in CO₂ emissions.

Finally, limitations in this study’s methodology suggest issues that remain for future studies. First, I aggregated industrial sectors to 57, even though the data sources contained richer information. Therefore, if we examined definitions of sectors in these sources in more detail, we might find an appropriate way to compile more detailed hybrid IO tables, which may consist of “Use” and “Make” matrices to clearly describe physical flows (e.g., Hannon et al. 1983; Casler and Wilbur 1984; Kagawa and Inamura 2001). In the same vein, evaluating the contributions from imported energy and commodities more precisely with a global hybrid MRIO table remains as a future challenge.

Second, two massive events, the Great Recession and the 2011 earthquake, occurred in Japan during the study period, but I was unable to distinguish the impacts of these two events empirically. One possible way to resolve this issue would be to employ the extended IO tables for Japan (METI 2021); these are issued annually in the intervening years between the 5-year regular IO tables with fewer datasets and compensating estimations. Thus, the extended IO tables may be combined with yearly energy-balance tables to increase the temporal resolution of the analyses (Su and Ang 2012b).

Third, although this study showed that renewable energies have played rather minor roles in the energy transition thus far, their roles will increase in the future, because, in addition to the cumulative effects of the FIT scheme, the Japanese prime minister declared in October 2020 that Japan aims to attain a carbon-neutral society by 2050 and to promote carbon-free energy to that end. In this connection, an appendix table on renewable energy has been improved within the energy balance table of Japan in recent years. Therefore, future studies may well be able to compile a hybrid table that describes renewable energies in more detail to follow transitions for renewables in the future.

Fourth, while this study sheds light on the energy supply structure among primary and secondary carriers, the effects of a change in supply chains connecting non-energy sectors need to be investigated more deeply, as Treloar (1997) and Oshita (2012) did using the structural path decomposition technique. In addition, this study’s examination on the effect of price changes on the energy transition remained somewhat rudimentary because IO analysis is generally not suitable for such a purpose. Therefore, further studies incorporating computable general equilibrium (CGE) models are recommended.

Fifth, the two massive events that occurred during this study period certainly impacted household economic activities, which are treated as exogenous in this study. For example, sudden declines in disposable income may have altered households’ consumption mix and level, perhaps with a larger share going towards necessities rather than luxury goods. As discussed in Sect. 1.2, the hybrid IO model cannot in principle evaluate the consumption mix or level effects. Therefore, the monetary IO model must be used within the SDA framework. More broadly, the Miyazawa model, which incorporates endogenous household sectors into an IO model (e.g., Miller and Blair 2009; Ueda et al. 2019), or a CGE model may be employed to investigate household behavior in depth in the face of massive events such as the Great Recession or the 2011 earthquake in Japan.

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Authors’ contributions Corresponding author TU solely conducted the analyses of this study and wrote the entire article.

Availability of data and materials All data sources employed in this study are publicly available at the URL in the reference list. The hybrid input-output tables compiled by the author are included in this article as Supplementary Material A.

Declarations

Conflict of interest The author declares he has no competing interests.

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