An Evaluation of Carbon Emission Changes in the Japanese Housing Sector from 1980-1995

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Abstract
Urban development has made life convenient and comfortable. Travel has become faster, communication has become easier. However, there are externalities that we need to face due to urban development; the ratification of the Kyoto Protocol and its recent enforcement has led signatory countries to limit and propose ways on how to achieve the reduction in emissions by 2012. One aspect of proposed reduction is to make urban development sustainable. Urban development is related to infrastructure systems that generations build for the improvement of the quality of life. Construction of residential and non-residential buildings in cities is part of the infrastructure systems that we need to assess to be able to achieve the 6% reduction limit of carbon emissions. This paper studies the changes of carbon emissions induced by residential construction. To be able to assess the future requirements of society in terms of infrastructure facilities and its sustainability, a study on the historical changes of carbon emissions and the relationship of material requirements to emissions are necessary. The Input-Output Approach coupled with Structural Decomposition Analysis (SDA) is used to analyze the impacts of Japanese residential construction on the environment. The changes in construction technology, emission structure and material manufacturing technology are studied in this paper. It can be shown that these changes contribute to the fluctuations in the carbon emissions from residential construction during the 15-year study period.

Keywords: residential building construction; structural decomposition analysis; environment; carbon emission intensity

1. Introduction
The recent enforcement of the Kyoto Protocol to mitigate the risk of climate change has led governments, who are signatory to the Pact, to hold in check their current emission levels and propose ways on how to limit their emissions. Infrastructure systems are necessary to the lives of human beings. However, the construction of infrastructure systems contributes to emissions into the environment. Buildings-related CO2 emissions account for one third of Japan's total CO2 emissions (Ikaga, et al, 2002). Due to the immensity of CO2 contribution from residential and non-residential construction, it is necessary to study the reasons for this huge contribution to CO2 emissions. This paper tries to study the changes of carbon emissions induced by residential construction for a 15-year time period. In order to reduce emissions from the construction sector, specifically the residential construction sector, it is necessary to have a historical perspective on how material requirements from housing construction contribute to increased or decreased emission levels. The relationship between the assessment of environmental loads and the economic system is modeled through the use of the Input-Output Methodology. The conventional Input-Output model has been employed to estimate environmental loads due to the production processes of the entire economic system. The comparison of changes in structure can be modeled through the structural decomposition analysis (SDA). It represents a way of distinguishing major sources of change in an economy. Several researches had been made in this area using the SDA methodology like Rose & Chen (1991); Fujimagari (1989); Skolka (1989); Weir (1998) and others. Dietzenbacher and Los (1998), moreover, showed a detailed sensitivity analysis of the decomposition. Gerilla, et al. (2000, 2001) studied the effects of historical and technological changes in the road construction industry, which made use of the rectangular input-output method. The sources of changes in carbon emission intensities induced by housing construction in Japan are studied from 1980 to 1995. A sensitivity analysis of changes in the input coefficients of the final demand converter and that of the total carbon emission intensity is also presented. The paper is organized as follows: the following section discusses the framework of the study. The decomposition of structural changes is done in Section 2. Following that is the empirical application of the model using the IO tables of Japan. Concluding comments close the paper in Section 4.
2 FRAMEWORK OF THE STUDY

2.1 Carbon Emission Model

The carbon emission model that is formulated in this paper incorporates the hierarchical relationship of the economic system. The procedure for getting the carbon emission model is shown in Fig. 1.

\[ \text{Eg}_{nc} = \text{Carbon emission coefficient vector of primary energy sector;} \]
\[ (I - A_{nc})^{-1} = \text{Hybrid total requirements matrix induced by the non-construction sector;} \]
\[ f_{nc} = \text{Final demand of the non-construction requirements of a residential construction commodity.} \]

The residential construction commodity used as final demand in this paper is composed of all residential buildings-related construction such as wooden construction, steel construction, reinforced concrete construction, concrete block construction and steel reinforced concrete construction. The final demand used for the production of a residential construction commodity is a final demand converter. A final demand converter is used because no detailed construction category is given in the basic I-O table. This converter is taken from the input transactions of the construction sector. The final demand converter used is the non-construction-input requirements of a residential construction commodity. The final demand converter can also be subdivided into each residential building construction category.

\[ f_{ic} = \frac{p^i_c}{\sum_i p^i_c} \]  (2)

where:
\[ p^i_c = \text{input coefficient from the industrial sector i for the building construction category c;} \]
\[ p^i_c = \text{cost of inputs from the industrial sector i for the construction category c.} \]

The final demand for a building construction commodity can be converted into the hybrid system as given in the vector:
\[ f_{ic}^{cs} = \left[ f_{ic}^{cs} \mid f_{ic}^{nc} \mid f_{ic}^{es} \right]^t \]  (3)

where:
\[ f_{ic}^{cs} = \text{final demand converter for every residential construction commodity c;} \]
\[ f_{ic}^{nc} = \text{Final demand of the primary energy industry requirements of a residential construction commodity;} \]
\[ f_{ic}^{es} = \text{Final demand of the non-construction industry requirements of a residential construction commodity;} \]
\[ f_{ic}^{es} = \text{Final demand of the construction industry requirements of a residential construction commodity;} \]

Note that the symbol (t) means the transpose of the vector. The final demand converter used is the non-construction-input requirements of a residential construction commodity. The final demand converter can also be subdivided into each residential building construction category.

2.2 Structural Decomposition Analyses

The carbon emission model is a function of the emission structure, non-construction technology and the residential construction technology. If we let \( L_{nc} = (I - A_{nc})^{-1}, \) the carbon emission model function is shown in equation (4).
\[ \text{CO}_{es} = f\left( \text{Eg}_{nc} L_{nc} f_{nc}^{es} \right) \]  (4)

The sources of changes in carbon emission intensity
are studied using the structural decomposition analysis (SDA). The total change in carbon emissions intensities is decomposed into effects caused by the changes in the emission structure of carbon producing sectors, $E_{\text{gnc}}$, changes in non-construction technology, $L_{\text{nc}}$, as well as changes in the construction technology of the residential construction, $f_{\text{nc}}^{c}$. Using equation (4), we can carry out its decomposition over time by

$$
\frac{\partial \text{CO}_{\text{es}}}{\partial t} = \frac{\partial E_{\text{gnc}}}{\partial t} L_{\text{nc}} f_{\text{nc}}^{c} + E_{\text{gnc}} \frac{\partial L_{\text{nc}}}{\partial t} f_{\text{nc}}^{c} + E_{\text{gnc}} L_{\text{nc}} \frac{\partial f_{\text{nc}}^{c}}{\partial t} \tag{5}
$$

This is a continuous function, since we are dealing with discrete time periods and the model is a static model, we define the discrete approximation of the continuous function as shown in equation (6)

$$
\Delta \text{CO}_{\text{es}} = E_{\text{gnc}1} L_{\text{nc}1} f_{\text{nc}1}^{c} - E_{\text{gnc}0} L_{\text{nc}0} f_{\text{nc}0}^{c} \tag{6}
$$

The subscripts 1 and 0 denote the future year $t_1$ and base year $t_0$, respectively. Equation (6) can be transformed into six different types of decomposition forms. We can explain these equations as the six different growth paths that lead to the reasons for carbon emission changes in Japan. $E_{\text{gnc}}$ represents the changes in the emission structure of the primary energy sector, while $L_{\text{nc}}$ represents the changes in the non-residential construction technology and $f_{\text{nc}}^{c}$ denotes the final demand changes of the non-residential construction requirements of a residential construction commodity. Dietzenbacher and Los (1998) suggested that the average of polar decompositions be computed for cases with more than two determinants. So the average effects of the determinants are computed. The average effects of the emission structure changes of the primary energy sectors can be calculated by the formula:

$$
\left(\frac{1}{6}\right) \left[ 2 \cdot \left( E_{\text{gnc}1} L_{\text{nc}1} f_{\text{nc}1}^{c} \right) + 2 \cdot \left( E_{\text{gnc}0} L_{\text{nc}0} f_{\text{nc}0}^{c} \right) \right] \tag{7}
$$

The average effects of the changes in non-construction technology are manifested in equation (8).

$$
\left(\frac{1}{6}\right) \left[ 2 \cdot \left( E_{\text{nc}1} L_{\text{nc}1} f_{\text{nc}1}^{c} \right) + 2 \cdot \left( E_{\text{nc}0} L_{\text{nc}0} f_{\text{nc}0}^{c} \right) \right] \tag{8}
$$

Equation (9) estimates the average effects of changes in residential construction technology.

$$
\left(\frac{1}{6}\right) \left[ 2 \cdot \left( E_{\text{nc}1} L_{\text{nc}1} \Delta f_{\text{nc}}^{c} \right) + 2 \cdot \left( E_{\text{nc}0} L_{\text{nc}0} \Delta f_{\text{nc}}^{c} \right) \right] \tag{9}
$$

It should be noted that the final demand used in the study is a final demand converter, which consists of the input coefficients of each residential building construction category, and in effect, can be called the changes in the residential construction technology for each residential building construction category.

3. EMPIRICAL RESULTS

The result of the calculations and analysis is presented in this section. The decomposition equations presented in section 2 are applied to the analysis of the changes in the carbon emission intensities for residential construction from 1980 to 1995. These periods were chosen to be able to trace the historical changes of carbon emissions in Japan induced by housing construction. The application of the decomposition equations are done for the residential building construction and its commodities.

3.1 Basic Data

The data used in the study were the basic commodity-by-commodity input-output tables from the Management and Coordination Agency; the energy usage by sectors based on the input-output analysis and the input tables for construction work from the Ministry of Construction (MOC), Japan. All the above-mentioned data were collected for the years 1980, 1985, 1990 and 1995.

The sector classification in the input-output tables for different years do not correspond to each other, therefore all the tables were aggregated into a 60 x 60 matrix for each analysis year. The aggregation was done to be able to make all the sectors uniform and manageable. Moreover, all monetary terms were converted to 1985 prices to facilitate comparison and to exclude price components from the analysis of structural change. The sectors were rearranged according to the primary energy sector (es), which is composed of coal mining, crude petroleum and natural gas, Limestone, petroleum refinery products, coal products, electricity and power generation and gas supply and steam. Two sectors are from the construction industry (cs) namely: the building construction sector and civil engineering construction sector, and lastly, the other 51 sectors are the non-construction (nc) sectors.

The residential building construction category was further divided into wooden construction, steel construction, steel reinforced (SRC) concrete construction, reinforced concrete (RC) concrete construction, reinforced concrete (RC) and concrete block (CB).
3.2 Carbon Emission Survey

Fig.2. shows the carbon emission intensity of residential construction for the 15-year study period. These intensities are based on 1985 constant prices. The figure also shows the intensities divided according to the primary energy sectors. The trend of carbon emissions can be seen from 1980 to 1995. During the 15-year period, the carbon emission intensity increased by about 66% for housing construction. Petroleum Refinery Products dominate the other primary energy sectors in the contribution to carbon emissions for the period. For 1980, petroleum refinery products contributed about 36% to the total emissions intensity; this is followed by coal products with about a 26% contribution. For 1985, petroleum refinery products contributed to about 29% to the total emissions while coal products contributed about 27%, these figures are slightly lower compared to those of 1980. For 1990, petroleum refinery products still dominated the other primary energy sectors but its contribution to the total emission intensity reduced to about 26%, the rise of the contribution of electricity (18%) in residential construction is seen in this year. The contribution of coal products and petroleum products to the emission intensity was 19% and 35%, respectively, for 1995.

Emission levels were at their lowest from 1985 to 1990, and there was a 27% decrease in emissions during this period. The decrease in emission intensities from 1980 to 1985 was not so drastic for residential construction (only 6%) The lowest emission intensity for the 15-year period was in 1990 with a 620 kg-C/MY intensity. The emission reduction by the Kyoto Protocol relative to 1990 levels is proper because of the lowest emission intensity during the period. However, it will be difficult to abide by the guideline because the carbon emission intensity increased in 1995 with an increase of as much as 145% from 1990 levels.

Fig.3. shows the carbon emission intensities of different residential construction commodities. Residential construction was divided into different types of construction according to the Ministry of Construction's input-output classification. The decomposed residential construction types are: wooden (W) construction, steel reinforced concrete construction (SRC), reinforced construction (RC), steel construction and concrete block (CB) construction.

For the 15-year period, it can be seen that steel residential construction had the highest emission intensity compared to other residential construction types. Steel residential construction dominated other residential construction types in all years. It had about a 23% share of the emissions for the study period. Steel reinforced concrete, reinforced concrete and concrete block construction have about a 22% and 21% and 20% contribution to the emission intensity, respectively. Wooden construction had only a 14% contribution to emission intensities during the 15-year period.

The change in emission intensities from 1985-1990 was also the highest for steel construction which had a 31% decrease. SRC and RC construction types contributed to a 29% decrease in emission intensities during this period. Wooden construction had a 27% decrease in emission intensity while the emission intensity for concrete block construction decreased by 18%. Emission intensity levels increased in 1995 for all types of residential construction. There was a 127% in emission intensities for steel construction; while SRC and RC had a 107% and 100% increase in carbon emission intensities, respectively. It is interesting to note that emissions from wooden residential construction surged in 1995 to about 193% compared to 1990.

The reasons for the fluctuations in emission intensities are discussed in the next section.

3.3 Results from the Decomposition Analysis

The results of the decomposition analysis of the structural
changes in carbon emission intensities induced by building construction are presented in this section. Table 1 shows the decomposition analysis for residential construction.

The total changes in carbon emissions ($\Delta$CO$_e$) for a certain time interval can be decomposed into changes in emission structure, $\Delta$E$_{gnc}$, changes in non-construction technology, $\Delta$A$_{nc}$, and changes in the input coefficients of residential construction, $\Delta$f$_{nc}$. Emission structure changes are sets of reciprocal action of the subsystems that induce carbon emissions. Changes in input coefficients of residential construction are basically changes in the residential construction technology.

The increase in carbon emissions from 1980 – 1995 is a result of the increase in the input coefficients of the residential construction; another reason for the increase is due to the emission structure; this might mean an increase in the residential construction industry’s usage in carbon intensive primary energy sources. It is important to note that a negative effect in carbon emission intensity resulted from the changes in non-construction technology. This negative effect is explained as improvement in the overall non-construction technology used for construction during this period.

The period from 1980-1985 indicates that the decrease in emission is mainly due to the change in the primary energy sectors’ emission structure. This reveals that dependence on energy intensive industries has waned and shifted to less energy intensive industries, which contributed to the decrease in carbon emissions. Another reason is the improvement of non-construction technology during this period.

The biggest dip in the emission change occurred during 1985-1990; this is the result of improvement in emission structure, non-construction technology and residential construction technology. This reflects increased industrial efficiency and productivity in residential construction design and methods. The slowing down of the economy due to the bursting of the bubble economy during this time maybe another reason for the change in the input coefficients of residential construction.

For 1990-1995, a drastic increase in carbon emission intensity occurred as compared to the previous period. This is due to the increase in final demand as well as increased change in the emission structure, and although the non-construction technology improved in this period it was offset by an increase in other variables.

The section 3.4 discusses the decomposition analysis of each residential construction type.
3.5 Sensitivity Analysis

A sensitivity analysis of the carbon emission intensity based on the input coefficient of residential construction was done to ascertain how much change in carbon emissions will occur for a change in the construction input coefficients. The construction input coefficients chosen are material inputs which contributed to the major increase in carbon emissions for 1990-1995 as seen in Table 3.

Table 2. Decomposition Analysis for Each Residential Construction Type (kg-C/MY)

| Period       | ΔFrc | ΔArc | ΔPr | ΔCOrc |
|--------------|------|------|-----|-------|
| W            |      |      |     |       |
| 1980-1985    | -144.74 | -11.59 | 104.4 | -51.92 |
| 1985-1990    | -43.94 | -61.76 | -88.11 | -193.8 |
| 1990-1995    | 699.7 | -146.66 | 458.58 | 1011.62 |
| SRC          |      |      |     |       |
| 1980-1985    | -166.25 | -59.74 | 47.79 | -178.2 |
| 1985-1990    | -92.98 | -105.99 | -84.43 | -283.4 |
| 1990-1995    | 435.29 | -99.95 | 382.92 | 718.26 |
| S            |      |      |     |       |
| 1980-1985    | -171.52 | -48.87 | 85 | -135.4 |
| 1985-1990    | -87.68 | -93.06 | -100.91 | -281.65 |
| 1990-1995    | 435.11 | -98.19 | 335.69 | 672.61 |
| CB           |      |      |     |       |
| 1980-1985    | -194.87 | -29.82 | 52.83 | -171.86 |
| 1985-1990    | -81.7 | -78.67 | -11.07 | -171.86 |
| 1990-1995    | 419.55 | -104.55 | 441.83 | 756.82 |

levels of steel residential construction can be controlled with the monitoring of the usage of these materials for construction.

As seen in Fig.4., carbon emission intensity embedded in timber and its products is highly sensitive to small changes in the input coefficient of timber and its products. We see that if we reduce the input coefficient of timber by 50% the change in the total carbon emission intensity will be reduced by about 2.5%. Similarly, carbon emission from cement and cement products are also sensitive. An increase in the input coefficient of cement and cement products by 50% will generate an increase in carbon emission intensity by 1.6%. The carbon emission intensity of the other material/services input like metal products for construction and transportation are not so sensitive to the changes in its input coefficient.

Fig.4. illustrates the result of the sensitivity analysis. The abscissa in the graph is the residential construction input coefficient while the ordinate shows the carbon emission intensity. The values for the x-axis show a decrease or increase from the current input coefficient (1). A value of 1.1 in x shows a 10 percent increase in the input coefficient of a certain material input. The sensitivity analysis was such that when an input fnci is altered, the other input coefficients are also changed according to the scale of its contribution to the sum of the input coefficients.

Knowing the sensitivity of the carbon emissions to changes in the material/services input coefficients is important in determining which sector should be focused on when trying to reduce the carbon emissions from building construction. A design of residential buildings using different types of materials which are not so carbon intensive/sensitive can be another way of trimming down carbon emissions.
construction contributed to a great extent to the increase in carbon emissions in residential building construction.

The 15-year analysis period shows that carbon emission intensity significantly increased for residential construction. The reasons for the increase were the increase in the input coefficients of the residential building construction. Another reason is the increase in the emission structure; this means an increase in the residential building construction industry's usage in carbon intensive primary energy sources, mainly petroleum refinery products. It is worthy to note that during the 15-year period, material and manufacturing technology for residential building construction improved extensively. The greatest improvement in residential construction technology can be seen in the period of 1985-1990 where the greatest decrease in emissions can be seen. This improvement led to a decrease in emission levels. This reflects increased industrial efficiency and productivity in construction design and methods. The slowing down of the economy due to the bursting of the bubble economy during this time maybe another reason for the change in the input coefficients in residential building construction. The shifts in usage of primary energy also led to a decrease in carbon emission levels. It can be seen that timber and timber products, metal products for construction, furniture and fixtures, cement and transportation were the top 5 material/service inputs which led to the increase in carbon emission. The small and large changes in the usage of some materials, like timber and its products and cement and its products, led to a drastic change in carbon emissions compared to other material/services inputs. Knowing the sensitivity of the carbon emissions to changes in the material/services input coefficients is important in determining which sector should be focused on when trying to reduce the carbon emissions from residential building construction. Design of buildings using different types of materials, which are not so carbon intensive/sensitive can be another way of trimming down carbon emissions.

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