An evaluation of inclusive capital stock for urban planning

Fujii, Hidemichi and Managi, Shunsuke

August 2016

An evaluation of inclusive capital stock for urban planning

Hidemichi Fujii[1], Shunsuke Managi[2,3*]

[1] Graduate School of Fisheries and Environmental Sciences, Nagasaki University, 1-14 Bunkyo-machi, Nagasaki 852-8521, Japan
E-mail: hidemichifujii@nagasaki-u.ac.jp

[2] Urban Institute & Department of Urban and Environmental Engineering, School of Engineering, Kyushu University, 744 Motooka, Nishiku, Fukuoka, 819-0395, Japan.

[3] QUT Business School, Queensland University of Technology, Level 8, Z Block, Gardens Point, 2 George St, Brisbane QLD 4000, Australia
E-mail: managi.s@gmail.com
* Corresponding Author

Abstract

Rapid urbanization has caused significant problems, and sustainable city design can play an important role in solving these problems under limited budgets and resources. Previous studies have proposed city evaluation indicators that can suggest appropriate urban designs. However, these indicators do not clearly consider economic theory, which is crucial for understanding accumulation of urban capital stock by the flows from daily urban activities. This study proposes a research framework based on economic theory for evaluating urban sustainability; this framework uses the inclusive wealth index (IWI) concept to examine inclusive urban capital stock. It examines the advantages of using the IWI as a city evaluation indicator along with data envelopment analysis and a decomposition analysis framework. We use data for 20 Japanese ordinance-designated cities for an empirical study to demonstrate a proposed approach for evaluating inclusive urban capital. The developed research application evaluates each city's relative superiority in terms of capital accumulation and identifies those factors determining changes in capital flows via changes in efficiency, priority, and scale. The combination of these results can be helpful to decision makers seeking to increase urban capital by considering reference city information and relative superiority.

Keywords: inclusive urban capital, urban planning, sustainability, decomposition analysis, data envelopment analysis

1. Introduction

Rapid urbanization has caused significant problems in terms of food security, resource availability, environmental pollution, employment, and living conditions (UNEP 2012). Sustainable city design has recently received significant academic and policy attention due to the increasing complexity of cities considering various aspects such as living, labor, transport, and the environment (Mori and Yamashita 2015, Managi 2016). Rapid urban development needs extensive natural resources and major government budget allocations to maintain the regional environment, but government budgets and natural resource are limited. Therefore, efficient spending and resource use are important factors for achieving sustainable urban development.

To understand the effect of urban planning policies on sustainability, it is important to use a comprehensive target index that covers the various urban factors. An evaluation index helps policy makers to consider the urban context. Additionally, an urban policy that refers to only one dimension might worsen other factors. Many city evaluation indexes have been developed in previous studies; table 1 shows a list of proposed city evaluation indexes, focusing on the purpose, key evaluation dimensions, and the aggregate of the total score.

<Table 1 about here>

The city evaluation indexes listed in table 1 mainly apply flow data related to economic, social, and environmental factors. Some indexes evaluate capital stock (e.g., GCCI evaluates human capital, GPI evaluates infrastructure development). However, none of these indexes explicitly looks at human, environmental, and produced capital stocks. Dasgupta et al. (2015) pointed out the problem with using flow data in evaluation frameworks: “GDP does not record the depreciation of capital assets even though GDP can increase despite the depletion of natural resources.” Economic theory offers advantages when evaluating urban capital stock, as it considers the relationship between flow and capital data. Economic theory (e.g., Dasgupta et al. 2015) justifies the use of this inclusive capital measure to assess sustainable development. Once there is a positive increase in stock value, which is its shadow price multiplied by each stock measure, it can assist in identifying what subjects the policy needs to support each problem. However, the existing city evaluation indexes shown in table 1 are limited in their use of economic theory to measure sustainability. One potential cause of this is the limited availability of capital stock data from national statistical databases.

This study proposes a tool for evaluating inclusive urban capital stock using the inclusive wealth index (IWI) and based on economic theory. The IWI is theoretically developed by Dasgupta et al. (2015) and empirically elaborated by UNU-IHDP and UNEP (2012, 2014) (see Managi (2015, 2016) for a review). We define inclusive urban capital as capital stock as estimated by the IWI to be used for urban planning to achieve sustainable urban design. We define sustainability of societal development along which (intergenerational) well-being does not decline (UNU-IHDP and UNEP 2014).[1]

Our main objective is to propose an IWI application for urban planning. To explain the proposed application, we introduce an empirical analysis using data for 20 Japanese cities. Dasgupta et al. (2015) noted that governments need a measurement tool that comprehensively records wealth, including reproducible capital, human capital, and natural capital, to measure sustainable progress. The advantage of the IWI is that it considers natural capital, human

[1] As UNU-IHDP and UNEP (2014) point out, “Wealth accounting also internalizes sustainability by tracking the changes in the value of a nation’s capital asset stocks”. Thus, considering the change in the IWI would be a useful tool for evaluating a change in sustainability.

capital, and produced capital, which are considered to be the key factors in conventional city evaluation approaches (see UNU-IHDP and UNEP 2014, Managi 2015).[2]

2. The Inclusive wealth index (IWI) for urban planning

2-1. The evaluation of inclusive urban capital stock

(1) What is an effective way to increase inclusive urban capital? and (2) what drives changes in inclusive urban capital stock? Three factors characterize capital stock. The first is the volume of capital stock, which indicates whether the capacity or wealth of cities is maintained over time. The second is the balance of capital stock, which reflects the urban planning vision and urban characteristics. These are important pieces of information for selecting the reference city for urban policy. The third is the efficiency of capital stock use, which shows the capital productivity of cities.

2-2. Comparing capital stock between cities

To evaluate the first and second factors, the results of the IWI estimation score can be directly applied. The volume factor can be evaluated using the capital stock per person, and the balance of capital stock can be evaluated using a share of each capital stock. These two approaches for country data were introduced as the inclusive wealth of nations in section 3 of Chapter 1 in UNU-IHDP and UNEP (2014).

[2] The IWI also offers advantages by evaluating ecosystem services using economic theory. The IWI evaluation framework introduces the shadow price approach to evaluate ecosystem services. The shadow price reflects the marginal value contribution to intergenerational well-being for a unit change in the respective capital asset (UNU-IHDP and UNEP 2014). Therefore, an ecosystem evaluation approach using shadow prices captures human behavior and preferences in monetary terms, allowing easy comparison with other monetary data. Costanza et al. (1997) pointed out that the total value of ecosystem services can be derived from shadow prices for all of the flows between processes as well as for the net outputs of the system. Therefore, we can understand natural capital stock, including ecosystem services, in monetary terms by multiplying the shadow price of exhaustible resources and that of environmental pollution by the volume of the resource stock and emissions.

However, each dimension of inclusive urban capital stock assumes a different role in sustainable urban development, and the relative advantage of urban characteristics differs across cities. Meanwhile, a direct comparison of volume factors may not sufficiently clarify the relative superiority of urban capital. Thus, we propose the relative superiority evaluation approach using the concept of inclusive urban capital stock.

To evaluate the relative superiority of urban capital stock, we adopt an empirical evaluation approach to city performance that uses the DEA method and the three inclusive capital stock per capita factors estimated by the IWI as output. This relative evaluation framework for multiple dimension factors is developed by Despotis (2005). The DEA approach was developed by Charnes et al. (1978) and has the advantage of using data from multiple inputs and outputs for the evaluation (Cook et al. 2014).

We set the three inclusive urban capital stock per capita factors as output. Under this setting, the integrated evaluation score for the accumulation of inclusive urban capital stock per capita of city k can be described as follows:

Objective function: Max. $\beta_k = w_p Produced\ capital_k + w_h Human\ capital_k + w_n Natural\ capital_k$ (1)

s.t.

$$w_p Produced\ capital_j + w_h Human\ capital_j + w_n Natural\ capital_j \leq 1 \quad (j = 1,2,\cdots,k,\cdots,J) \quad (2)$$

$$w_p, w_h, w_n \geq 0 \quad (3)$$

where β is the integrated evaluation score defined from zero to one. β=1 represents prolific inclusive capital accumulation per citizen, and a lower β represents relatively less capital accumulation compared with an efficient city. w_p, w_h, w_n indicate the variable weight for produced capital, human capital, and natural capital, respectively. j is the reference city name ($1 \leq j \leq J$), and k is the target city name. To estimate the integrated capital accumulation score for all cities, the DEA model needs to be applied independently to each of the J cities.

The variable weight is defined as a non-negative number and represents the relative superiority of capital accumulation compared with other cities. Therefore, the combination of the three variable weights characterizes a city's capital accumulation portfolio. The above primal DEA model can be transformed into a dual DEA model as follows.

$$\text{Objective function:} \qquad \text{Max.}\, \theta_k \tag{4}$$

s.t.

$$\sum_{j=1}^{j=J} \lambda_j Produced\ capital_j \geq \theta_k Produced\ capital_k \tag{5}$$

$$\sum_{j=1}^{j=J} \lambda_j Human\ capital_j \geq \theta_k Human\ capital_k \tag{6}$$

$$\sum_{j=1}^{j=J} \lambda_j Natural\ capital_j \geq \theta_k Natural\ capital_k \tag{7}$$

$$\sum_{j=1}^{J} \lambda_j = 1 \tag{8}$$

$$0 \leq \lambda_j \leq 1 \qquad\qquad j = 1, \cdots, k, \cdots, J \tag{9}$$

where θ is the integrated evaluation score and is equal to β. λ is the intensity weight variable for frontier line construction by an efficient city. n is the reference city name $(1 \leq$

$n \leq N$), and k is the target city name. To estimate the integrated capital accumulation score for all cities, the DEA model needs to be applied independently to each of the N cities.

Cities can use their reference city as a benchmark for comparison; if they can catch up to their benchmark city, they will be able to increase their integrated evaluation score in our model. The reference city can be identified from the λ score: λ_j is positive if city j is evaluated as efficient and observed as the reference city. In the dual DEA model, the reference city is selected from among cities with a similar portfolio of capital accumulation. Therefore, it becomes relatively easy to take action to improve capital accumulation in inefficient cities based on the policies of the reference city, as these cities share similar characteristics.

2-3. Decomposition analysis of urban capital stock change

The two DEA models provide the relative superiority of and the references for each city's capital accumulation. Although this approach offers an advantage by evaluating the volume of capital stock per capita, it is still difficult to clarify why urban capital stock changes. The main factors affecting changes in inclusive urban capital stock differ between cities, and they depend on the city's characteristics and urban planning strategy. To understand the factors that change urban capital stock, we propose taking a decomposition approach, focusing on the efficiency and the priorities of government budget expenditures. We choose efficiency and priorities of government expenditures because government planning is expected to increase the value of the region, which needs each expenditure to support its activity.

To decompose changes in urban capital stock, the following three indicators are used: (1) the efficiency of government budget use (EFFICIENCY), (2) the priorities in government budget allocation (PRIORITY), and (3) the scale of the government budget (SCALE). We defined the EFFICIENCY indicator as the change in urban capital stock divided by government budget expenditure, and it represents the efficiency of budget usage for urban capital stock growth. This indicator can increase for two reasons: urban capital stock growth while maintaining the same budget or budget expenditure reduction while maintaining urban capital stock. The reduction of expenditures can be achieved by effectively using the budget to increase urban capital stock.

The PRIORITY indicator is calculated as the budget expenditure for a specific area (e.g., education and health) divided by the total budget expenditure and represents the share of the budget allocated to that specific area. The PRIORITY indicator reflects the relative priority of budget allocations in urban planning. Finally, the SCALE indicator shows the scale of urban planning capacity, which is the total amount of urban budget expenditures.

Here, we introduce the equation for the decomposition analysis of the IWI change in human capital stock $\varDelta \mathrm{IWI}_{\mathrm{Human}}^{t,t+1}$ $(= \mathrm{IWI}_{\mathrm{Human}}^{t+1} - \mathrm{IWI}_{\mathrm{Human}}^{t})$. Equation (10) represents the decomposition model for change in human capital stock using three factors.

$$\begin{aligned} \varDelta \mathrm{IWI}_{\mathrm{Human}}^{t,t+1} &= \frac{\varDelta \mathrm{IWI}_{\mathrm{Human}}^{t,t+1}}{\mathrm{Budget}_{\mathrm{Human}}^{t}} \times \frac{\mathrm{Budget}_{\mathrm{Human}}^{t}}{\sum_{\mathrm{i}} \mathrm{Budget}_{i}^{t}} \times \sum_{\mathrm{i}} \mathrm{Budget}_{i}^{t} \\ &= \mathrm{EFFICIENCY}_{\mathrm{Human}}^{t} \times \mathrm{PRIORITY}_{\mathrm{Human}}^{t} \times \mathrm{SCALE}^{t} \qquad (10) \end{aligned}$$

where $\varDelta \mathrm{IWI}_{\mathrm{Human}}^{t,t+1}$ is the change in urban capital stock in terms of human capital, and i is the type of budget expenditure. The change in capital stock can be understood as a capital flow, considering the depreciation of stock. Government budget expenditures increase capital flows but do not directly increase capital stock. Thus, it is consistent to evaluate the efficiency of government budget use focusing on the capital flow per budget expenditure in each field.

Next, we use the decomposition analysis framework to explain changes in capital flows. To understand the equation more easily, we set the variables as follows. The flow of human capital from year t to year t+1 is F_H^t $(= \varDelta IWI_{Human}^{t,t+1})$, budget use efficiency for human capital in year t is E_H^t $(= EFFICIENCY_{Human}^t)$, the priority of budget spending on human capital in year t is P_H^t $(= PRIORITY_{Human}^t)$, and the scale of the government budget is St $(= SCALE^t)$. In this case, we obtain $F_H^t = E_H^t \times P_H^t \times S^t$.

Next, we set the change in the flow of human capital as $\varDelta F_H^{t,t+1} = (= F_H^{t+1} - F_H^t)$; then, we obtain equation (11).

$$\varDelta F_H^{t,t+1} = F_H^{t+1} - F_H^t = E_H^{t+1} \times P_H^{t+1} \times S^{t+1} - E_H^t \times P_H^t \times S^t \tag{11}$$

Here, we set the change of each indicator as $\varDelta E_H^{t,t+1} = E_H^{t+1} - E_H^t$, $\varDelta P_H^{t,t+1} = P_H^{t+1} - P_H^t$, $\varDelta S^{t,t+1} = S^{t+1} - S^t$. Then, we obtain equation (12) by applying the Laspeyres index type decomposition approach.

$$\begin{aligned}
\varDelta F_H^{t,t+1} &= E_H^{t+1} \times P_H^{t+1} \times S^{t+1} - E_H^t \times P_H^t \times S^t \\
&= (E_H^t + \varDelta E_H^{t,t+1}) \times (P_H^t + \varDelta P_H^{t,t+1}) \times (S^t + \varDelta S^{t,t+1}) - E_H^t \times P_H^t \times S^t \\
&= \varDelta E_H^{t,t+1} \times P_H^t \times S^{t+1} + E_H^t \times \varDelta P_H^{t,t+1} \times S^t + E_H^t \times P_H^t \times \varDelta S^{t,t+1} + \varDelta E_H^{t,t+1} \times \varDelta P_H^{t,t+1} \times S^{t+1} \\
&= E_H^t \times \varDelta P_H^{t,t+1} \times \varDelta S^{t,t+1} + \varDelta E_H^{t,t+1} \times P_H^t \times \varDelta S^{t,t+1} + \varDelta E_H^{t,t+1} \times \varDelta P_H^{t,t+1} \times \varDelta S^{t,t+1}
\end{aligned} \tag{12}$$

Following Sun (1998), we transform equation (12) into equation (13) by allocating the interaction term.

$$\Delta F_H^{t,t+1} = \underbrace{\Delta E_H^{t,t+1} \times P_H^t \times S^{t+1} + \frac{1}{2}\left(\Delta E_H^{t,t+1} \times \Delta P_H^{t,t+1} \times S^{t+1} + \Delta E_H^{t,t+1} \times P_H^t \times \Delta S^{t,t+1}\right) + \frac{1}{3}\Delta E_H^{t,t+1} \times \Delta P_H^{t,t+1} \times \Delta S^{t,t+1}}_{\text{Efficiency change effect } (\Delta ECE)}$$

$$+ \underbrace{E_H^t \times \Delta P_H^{t,t+1} \times S^t + \frac{1}{2}\left(\Delta E_H^{t,t+1} \times \Delta P_H^{t,t+1} \times S^{t+1} + E_H^t \times \Delta P_H^{t,t+1} \times \Delta S^{t,t+1}\right) + \frac{1}{3}\Delta E_H^{t,t+1} \times \Delta P_H^{t,t+1} \times \Delta S^{t,t+1}}_{\text{Priority change effect } (\Delta PCE)}$$

$$+ \underbrace{E_H^t \times P_H^t \times \Delta S^{t,t+1} + \frac{1}{2}\left(\Delta E_H^{t,t+1} \times P_H^t \times \Delta S^{t,t+1} + E_H^t \times \Delta P_H^{t,t+1} \times \Delta S^{t,t+1}\right) + \frac{1}{3}\Delta E_H^{t,t+1} \times \Delta P_H^{t,t+1} \times \Delta S^{t,t+1}}_{\text{Scale change effect } (\Delta SCE)} \quad (13)$$

In this transformation, we allocate the second-order interaction terms and the third-order interaction term equally to each decomposed factor. This allocation of interaction terms follows the complete decomposition model developed by Sun (1998).

Therefore, the change in the human capital flow ($\Delta F_H^{t,t+1}$) is decomposed into changes in budget use efficiency (ΔECE, first term), changes in the human capital priorities in budget allocation (ΔPCE, second term), and changes to the government budget scale (ΔSCE, third term). Considering the three decomposed factors within the inclusive urban capital flow, we can understand why each city's capital accumulation changed. Additionally, considering the relative superiority of capital accumulation and the reference city information from the DEA model, the preferable urban planning practice would be to increase inclusive wealth by referring to the reference city's activities. Figure 1 shows a diagram outlining the approaches to explaining the relationship between DEA and decomposition analysis using the IWI as inclusive urban capital.

<Figure 1 about here>

3. Case study for a Japanese ordinance-designated city

3-1. Data description for the empirical study

In this section, we demonstrate our approach using data for 20 Japanese ordinance-designated cities. A Japanese ordinance-designated city is a city that has a population larger than 50 thousand and that has been designated through a Local Autonomy Act. We obtain the city level IWI data from Managi (2016), which estimates the IWI following UNU-IHDP and UNEP (2014). Local government budget expenditure data are observed from the regional statistics database in the social and demographic statistics published by the Statistics Bureau, Ministry of Internal Affairs and Communications, Japan. All monetary data are deflated to 2010 prices. To apply decomposition analysis to the government budget expenditure, we categorized it into four groups: human capital investment, produced capital investment, natural capital investment, and others. We provide the integration of each budget expenditure group in the appendix.

Table 2 shows the basic information for the 20 cities. From table 2, it can be seen that there is diversity in the population and industry structures among the cities. Kita-Kyushu has a high ratio of the population over 65 years old, while Kawasaki and Fukuoka have a low ratio. Saitama, Yokohama, Sagamihara, Kawasaki, and Sakai have a low day population ratio: these cities are located near Tokyo and Osaka, and many citizens commute to these larger cities. Niigata, Hamamatsu, and Kumamoto are active in the agricultural industry. Kawasaki, Hamamatsu, and Sakai have a high labor share in secondary industries compared to the others.

<Table 2 about here>

3-2. Empirical study for the relative evaluation of inclusive capital stock

Table 3 shows the relative evaluation results for inclusive capital stock accumulation using the DEA model. From table 3, Hamamatsu, Nagoya, and Osaka are evaluated as being efficient cities. The efficiency score represents the achieved urban capital accumulation per capita compared with a reference point determined by the efficient cities. The weight portfolio and the intensity of the reference city represent the relative superiority and the reference point information, respectively. The summation of both variables are equal to one.

<Table 3 about here>

The weight portfolio shows the relative superiority of capital accumulation per capita. Capital with a high weight score represents a strength of the city relative to others. For example, Sapporo has a greater relative advantage in produced capital accumulation than it has in human or natural capital. Hamamatsu has a relative advantage in natural capital accumulation. One interpretation of this result is that Hamamatsu has a large share in the agricultural industry. Similarly, a high weight for natural capital is observed in Niigata and Kumamoto, which are both popular agricultural areas. Thus, these three cities have a relative superiority in natural capital accumulation because they have active agricultural industries.

The weight score for human capital accumulation is high in Saitama, Yokohama, Kawasaki, and Nagoya. These four cities all have high income per capita (see table 2) in common. A high income family can allocate a sufficient portion of the household budget to education and health maintenance, which contribute to increasing human capital accumulation. Therefore, high income cities have a relative superiority in human capital accumulation.

The pattern for the reference city correlates with the weight portfolio. For example, Yokohama and Kawasaki, which observed high weight scores in human capital accumulation, tend to select Nagoya as a reference city. This high intensity score means that the integrated evaluation score and weight portfolio are reflected in the reference city's characteristics. The assignment of the reference city reflects its relative superiority to the objective city. Additionally, the characteristics of capital accumulation for the objective city are similar to those of the reference city. In our model, the benchmark city is selected from a set of relatively similar cities, and therefore, we compare one city to other cities with similar components of capital. Thus, our model is valid to understanding the integrated evaluation score and benchmarking.

We should note that the DEA approach limits the number of variables. Cook et al. (2014) discussed the limitations of the nonparametric production frontier approach: "it is likely that a significant portion of decision-making units (DMUs) will be deemed as efficient if there are too many inputs and outputs given the number of DMUs". Nonparametric frontier analysis, including the DEA approach, has difficulty evaluating small sample datasets.

3-3. Empirical study for a decomposition analysis of inclusive capital stock

Figures 2 to 4 show the results of the decomposition analysis for produced capital, human capital, and natural capital, respectively. The blue dot in the figures indicates the change in the inclusive urban capital flow between the first period (2000 to 2005) and the second period (2005 to 2010). The bar chart shows the contribution of each factor, and the summation of the bar chart equals the score represented by the blue dot.

From figure 2, it can be seen that the changes in produced capital flow are diverse among cities. Produced capital flow growth is mainly achieved by increasing the efficiency change effect (⊿ECE). Meanwhile most cities observed a negative effect from changes to the priorities in government budget expenditures (⊿PCE). One interpretation of the growth of ⊿ECE is the unit cost decline due to technological progress in civil engineering fields (OECD 2008). Technological progress in infrastructure building contributes to cost reduction and improved convenience and endurance.

Osaka, which has relative superiority in produced capital accumulation, increased capital flow through efficiency improvement. The types of government efforts and urban policies used in Osaka will be more effective when applied to cities with similar characteristics. As we explained in section 3.2, the reference city tends to have characteristics similar to those of the target city. From table 3, Sapporo, Sendai, and Fukuoka selected Osaka as a reference city. The common characteristic is that each of these four cities is the largest in its respective region. To efficiently increase produced capital flows with a limited government budget, we suggest that these three cities refer to the policies and government activities in Osaka as helpful information.

Niigata increased produced capital flow due to an increased priority in the budget expenditures, and the budget scale increased while the ⊿ECE was negatively affected, which made it difficult to maintain capital accumulation given a limited future budget. This trend is not seen in the other cities. This trend occurred because Niigata's local government budget needed to allocate more to human health and welfare for its aging population. Therefore, our results suggest that Niigata should refer to the urban planning policies and efforts in Hamamatsu, which is its reference city.

<Figure 2 about here>

Next, we discuss the changes to the flows of human capital (Figure 3) and natural capital (Figure 4). Figure 3 shows that many cities decreased their human capital flow due to negative ⊿ECE, especially Sapporo. The main reason for this decrease in the human capital flow is that low fertility has become more serious in Japan. Another possibility is the growth of the aging population. The main factor decreasing the human capital flow in Sapporo is a decline in the health capital flow due to a lower quality of life (see Managi 2016).

From Figure 4, the natural capital flow increased in many cities due to ⊿ECE growth. The unique point is that Sapporo increased natural capital flow as its ⊿PCE increased. Meanwhile, Hamamatsu, which is the reference city of Sapporo, successfully increased natural capital stock through ⊿ECE improvement. These results imply that Sapporo has the potential to increase natural capital stock while lessening the budget priority by referring to the urban planning effort in Hamamatsu city.

As the above empirical study shows, a decomposition analysis of capital flows can be used to evaluate urban planning efforts from comprehensive viewpoints using the IWI. Additionally, the results of the DEA model, in terms of relative superiority and reference city information, are readily available. By combining the results of the decomposition analysis and the DEA model, we can provide helpful information for sustainable urban planning and policy construction.

<Figure 3 and 4 about here>

4. Discussion and conclusion

Mori and Christodoulou (2012) identified the issues with city evaluation indexes. They reviewed 14 sustainability indexes and noted that four factors should be included in a city evaluation: (1) considering the triple bottom line of sustainability, (2) creating the index for the expressed purpose of assessing urban sustainability, (3) capturing the effects of leakage on other areas in the environmental dimension, and (4) assessing the world's cities in both developed and developing countries in an equitable manner.

Inclusive urban capital considers economic components such as produced capital; social components, including health and education as human capital; and environmental components such as natural capital. Therefore, inclusive urban capital clearly considers the first criterion, the triple bottom line. Additionally, considering the second criterion, inclusive urban capital is created for the purpose of assessing urban sustainability and urban planning. However, inclusive urban capital does not meet third and fourth criteria. To meet these requirements, the following are needed.

To meet the third criterion, further research into the leakage effect in the environmental dimension should be conducted, focusing on networks within and between cities. These networks are highly developed due to the development of information and transportation technologies. Thus, it is not enough to evaluate one region or one city to understand urban sustainability because this clearly does not consider the network of cities. Therefore, further research focusing on city networks (e.g., trade, transportation, people-to-people exchange) is important to develop the evaluation application for urban sustainability.

Issues in meeting the fourth criterion are related to the limited data availability in developing countries because the IWI needs a wide range of data variables. The development of data estimation analysis is important to promoting future research addressing inclusive urban capital. In addition to the country level analysis introduced in UNU-IHDP and UNEP (2014), utilizing inclusive urban capital stock provides a comprehensive evaluation of city performance.

To apply inclusive urban capital stock to city design, a database must be constructed to estimate the IWI. Research focusing on the regional IWI has already been conducted in the transportation field in cities worldwide (Nakamura et al 2015), in the disaster management field in Japanese cities (Tanikawa et al. 2014), and on natural, human, and produced capital in the U.S. (UNU-IHDP and UNEP 2012). A large-scale city dataset is available from the OECD database, which includes 281 metropolitan areas in 29 countries (https://stats.oecd.org/Index.aspx?DataSetCode=CITIES). The data variables in this database are divided into eight categories, which include demographics, land cover, urban forms, territorial organization, economics, the environment, labor, and innovation. These variables provide helpful information for both estimating inclusive urban capital stock and considering the changes in capital flows.

Additionally, corporate financial and environmental databases are published with free access and downloadable data (Fujii and Managi 2016). The collaboration between corporate data and regional data will create a new data network useful for creating an effective business strategy that considers regional characteristics.

Finally, a limitation of the IWI evaluation method is that it has difficulty addressing non-marketable goods such as cultural and religious factors. According to Arrow et al. (2012), capital stock should be accumulated via investment created by allocating those resources with decreasing current consumption. In this sense, social capital, including cultural activities, might not be suitable for evaluation as capital stock in the IWI. However, religion and culture are important factors in the creation of human capital stock. Thus, further research should investigate a more comprehensive evaluation approach considering regional differences in culture and religion.

Acknowledgements

This research was funded by the Grant-in-Aid for Specially Promoted Research [26000001B]; the Ministry of Education, Culture, Sports, Science and Technology, and S15 of the Ministry of the Environment, Japan. The results and conclusions of this article do not necessarily represent the views of the funding agencies.

References

ARCADIS. 2015. Sustainable cities index: balancing the economic, social and environmental needs of the world's leading cities. https://s3.amazonaws.com/arcadis-whitepaper/arcadis-sustainable-cities-index-report.pdf

Arrow, K. J., P. Dasgupta, L. H. Goulder, K. J. Mumford, and K. Oleson. 2012. Sustainability and the measurement of wealth. Environment and Development Economics 17:317-353.

A.T. Kearney. 2014. Global cities index and emerging cities outlook: global cities, present and future. A.T. Kearney, Chicago, Illinois, U.S.

Charnes, A., W. W. Cooper, and E. Rhodes. 1978. Measuring the efficiency of decision making units. European Journal of Operational Research 2:429–444.

Cook, W. D., K. Tone, and J. Zhu. 2014. Data envelopment analysis: prior to choosing a model. Omega 44:1–4.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-260.

Dasgupta, P., A. Duraiappah, S. Managi, E. Barbier, R. Collins, B. Fraumeni, H. Gundimeda, G. Liu, and K. J. Mumford. 2015. How to measure sustainable progress. Science 350:748.

Despotis, D.K. 2005. A reassessment of the Human Development Index via data envelopment analysis. The Journal of the Operational Research Society 56: 969-980.

Fujii, H., and S. Managi. 2016. The trend of corporate environmental management study and database. Environmental Economics and Policy Studies. 18: 265-272.

Institute for Urban Strategies. 2013. Global power city index 2013. The Mori Memorial Foundation, Tokyo, Japan.

International Organization for Standardization. 2014. Sustainable development of communities: indicators for city services and quality of life, ISO 37120. International Organization for Standardization (ISO), Geneva, Switzerland.

López-Ruiz, V., J. Alfaro-Navarro, and D. Nevado-Peña. 2014. Knowledge-city index construction: an intellectual capital perspective. Expert systems with applications 41:5560–5572.

Managi, S. (Ed.) 2015. The economics of green growth: new indicators for sustainable societies. Routledge, New York, New York, USA.

Managi, S. (Ed.) 2016. The wealth of nations and regions. Routledge, New York, New York, USA.

Mori, K., and A. Christodoulou. 2012. Review of sustainability indices and indicators: towards a new City Sustainability Index (CSI). Environmental Impact Assessment Review 32:94-106.

Mori, K., and T. Yamashita. 2015. Methodological framework of sustainability assessment in City sustainability index (CSI): a concept of constraint and maximisation indicators. Habitat International 45:10-14.

Nakamura, H., T. Tamaki, H. Fujii, and S. Managi. 2015. Efficiency and emissions from urban transport: application to world city level public transportation. Working Paper.

Kyushu University, Fukuoka, Japan.

OECD [Organization for Economic Cooperation and Development]. 2008. OECD Economic Surveys: Japan 2008. OECD Publishing, Paris, France.

Sun, J.W. 1998. Changes in energy consumption and energy intensity: a complete decomposition model. Energy Economics. 20:85–100

Tanikawa, H., S. Managi, and C. M. Lwin. 2014. Estimates of lost material stock of buildings and roads due to the great East Japan earthquake and tsunami. Journal of Industrial Ecology 18:421-431.

The Economist Intelligence Unit. 2012a. Hot spots: Benchmarking global city competitiveness. http://www.citigroup.com/citi/citiforcities/pdfs/eiu_hotspots_2012.pdf

The Economist Intelligence Unit. 2012b. The green city index: a summary of the green city index research series. Siemens AG, Munich, Germany.

UNEP [United Nations Environment Program]. 2012. Sustainable, resource efficient cities – making it happen! United Nations Environment Program, Nairobi, Kenya.

UN-Habitat. 2012. State of the world's cities 2012/2013: prosperity of cities. United Nations Human Settlements Programme (UN-Habitat), Nairobi, Kenya.

UNU-IHDP [United Nations University International Human Dimensions Programme] and UNEP [United Nations Environment Program]. 2012. Inclusive wealth report 2012: measuring progress toward sustainability. Cambridge University Press, Cambridge, UK.

UNU-IHDP [United Nations University International Human Dimensions Programme] and UNEP [United Nations Environment Program]. 2014. Inclusive wealth report 2014 measuring progress toward sustainability. Cambridge University Press, Cambridge, UK.

Table 1. Literature review of city evaluation indexes

Author	Index name	Purpose	Key evaluation dimensions (factors or indicators)	Aggregation
A.T. Kearney (2014)	Global Cities Index (GCI)	To examine a city's current performance based on five key dimensions.	Business activities, Human capital, Information exchange, Cultural experience, and Political engagement	Weighted summation of five key evaluation factors
Institute for Urban Strategies (2013)	Global Power City Index (GPCI)	To evaluate the major cities of the world on their global potential and comprehensive power.	Economy, Research and development, Cultural interaction, Livability, Environment, and Accessibility	Sum of all scores of the key dimension factors
The Economist Intelligence Unit (2012a)	Global City Competitiveness Index (GCCI)	To rank cities according to their demonstrated ability to attract capital, businesses, talent and visitors.	Economic strength, Physical capital, Financial maturity, Institutional effectiveness, Social and cultural character, Human capital, Environmental and natural hazards, and Global appeal	Weighted summation of score for key dimension factors. Weighting is based on expert interviews
The Economist Intelligence Unit (2012b)	Green City Index (GrCI)	To make a major contribution to the debate about environmentally sustainable cities.	CO_2, Energy, Buildings, Transport, Waste and land use, Water, Air quality, and Environmental governance	Equally weighted summation of eight key evaluation factors rebased out of 100
UN-Habitat (2012)	City Prosperity Index (GPI)	To measure the prosperity factors at work in individual cities, which pinpoints areas for policy intervention.	Productivity, Quality of life, Infrastructure development, Environmental sustainability, Equity and social inclusion, and Governance and legislation	Geometric average of score for five prosperity factors
ARCADIS (2015)	Sustainable Cities Index (SCI)	To give a snapshot of sustainability in each city, choosing to reflect areas in which local authorities have the power to enhance the sustainability of their city.	Literacy, Education, Green spaces, Health, Dependency ratio, Income inequality, Work-life balance, Property prices, Transport infrastructure, Energy use and renewables mix, Natural catastrophe exposure, Air pollution, Greenhouse gas emissions, Solid waste management, Drinking water and sanitation, Energy efficiency, Importance to global networks, GDP per capita, Ease of doing business, and Cost of doing business	Addition of scores of sustainable cities indicators
International Organization for Standardization (2014)	ISO37120	To measure over a period of time the management performance of city services and quality of life of the city.	46 core indicators and 54 supporting indicators addressing the Economy, Education, Energy, Environment, Recreation, Safety, Shelter, Solid waste, Telecommunications and innovation, Finance, Fire and emergency response, Government, Health, Transportation, Urban planning, Wastewater, and Water and sanitation	Not aggregated into one index

Source: Author selected some of the indices introduced in López-Ruiz et al. (2014) and added recent indexes.

Note: GCI weights each factor as Business activities (30%), Human capital (30%), Information exchange (15%), Cultural experience (15%), Political engagement (10%).

Table 2. Basic data for 20 ordinance-designated cities in 2010

	Population	Ratio of population over 65 years old	Day populati on ratio	Income per capita	Labor share of the primary industry	Labor share of the secondary industry	Labor share of the tertiary industry
	1,000 persons	%	%	1,000 Yen	%	%	%
Sapporo	1,914	20.5	100.6	3,017	0.13	12.27	87.61
Sendai	1,046	18.3	107.3	3,230	0.09	11.73	88.18
Saitama	1,222	19.1	92.8	3,730	0.09	15.93	83.98
Chiba	962	20.7	97.5	3,618	0.15	13.71	86.14
Yokohama	3,689	20.0	91.5	3,883	0.09	17.11	82.79
Kawasaki	1,426	16.6	89.5	3,838	0.14	24.49	75.37
Sagamihara	718	19.2	87.9	3,315	0.37	23.60	76.03
Niigata	812	23.1	101.8	2,892	0.47	19.50	80.03
Shizuoka	716	24.6	103.3	3,168	0.20	22.89	76.92
Hamamatsu	801	22.6	99.7	3,079	0.47	31.11	68.42
Nagoya	2,264	20.8	113.5	3,705	0.03	17.91	82.06
Kyoto	1,474	22.4	108.5	3,317	0.08	17.58	82.33
Osaka	2,665	22.5	132.8	3,132	0.04	17.31	82.65
Sakai	842	22.5	94.4	3,281	0.13	24.77	75.10
Kobe	1,544	22.9	102.6	3,516	0.09	15.85	84.06
Okayama	710	21.3	104.2	3,088	0.25	17.85	81.90
Hiroshima	1,174	19.7	102.1	3,281	0.14	17.34	82.52
Kita-Kyushu	977	25.1	102.7	2,974	0.09	21.34	78.57
Fukuoka	1,464	17.4	111.9	3,305	0.07	12.54	87.40
Kumamoto	734	20.8	N.A.	2,994	0.49	13.29	86.22

Table 3. Relative evaluation score of the inclusive urban capital stock

City name	Integrated evaluation score	Weight portfolio (w)			Intensity of reference city (λ)		
		Human capital	Produced capital	Natural capital	Hamamatsu	Nagoya	Osaka
Sapporo	0.530	0.000	0.894	0.106	0.323	0.000	0.677
Sendai	0.667	0.149	0.798	0.052	0.235	0.006	0.760
Saitama	0.657	0.993	0.000	0.007	0.076	0.924	0.000
Chiba	0.605	0.190	0.776	0.034	0.148	0.587	0.265
Yokohama	0.646	0.997	0.000	0.003	0.030	0.970	0.000
Kawasaki	0.651	0.999	0.000	0.001	0.007	0.993	0.000
Sagamihara	0.669	0.967	0.000	0.033	0.415	0.585	0.000
Niigata	0.795	0.000	0.745	0.255	0.777	0.000	0.223
Shizuoka	0.952	0.953	0.000	0.047	0.583	0.417	0.000
Hamamatsu	1.000	0.000	0.000	1.000	1.000	0.000	0.000
Nagoya	1.000	1.000	0.000	0.000	0.000	1.000	0.000
Kyoto	0.608	0.000	0.852	0.148	0.450	0.000	0.550
Osaka	1.000	0.000	1.000	0.000	0.000	0.000	1.000
Sakai	0.644	0.996	0.000	0.004	0.037	0.963	0.000
Kobe	0.659	0.153	0.835	0.012	0.051	0.198	0.751
Okayama	0.792	0.191	0.744	0.066	0.291	0.483	0.226
Hiroshima	0.762	0.000	0.865	0.135	0.409	0.000	0.591
Kita-Kyushu	0.530	0.153	0.821	0.026	0.115	0.147	0.738
Fukuoka	0.641	0.000	0.979	0.021	0.062	0.000	0.938
Kumamoto	0.578	0.000	0.860	0.140	0.425	0.000	0.575
20 city average	0.719	0.387	0.508	0.104	0.272	0.364	0.365

Note 1: The integrated evaluation score is defined from zero to one, and a higher score represents more urban capital stock per capita.

Note 2: The summation of the weight portfolio equals one. The type of capital stock with the highest weight score has relative superiority over the others.

Note 3: The summation of the intensity of the reference city equals one. The city with the highest intensity score shares the most similar characteristics with its objective city.

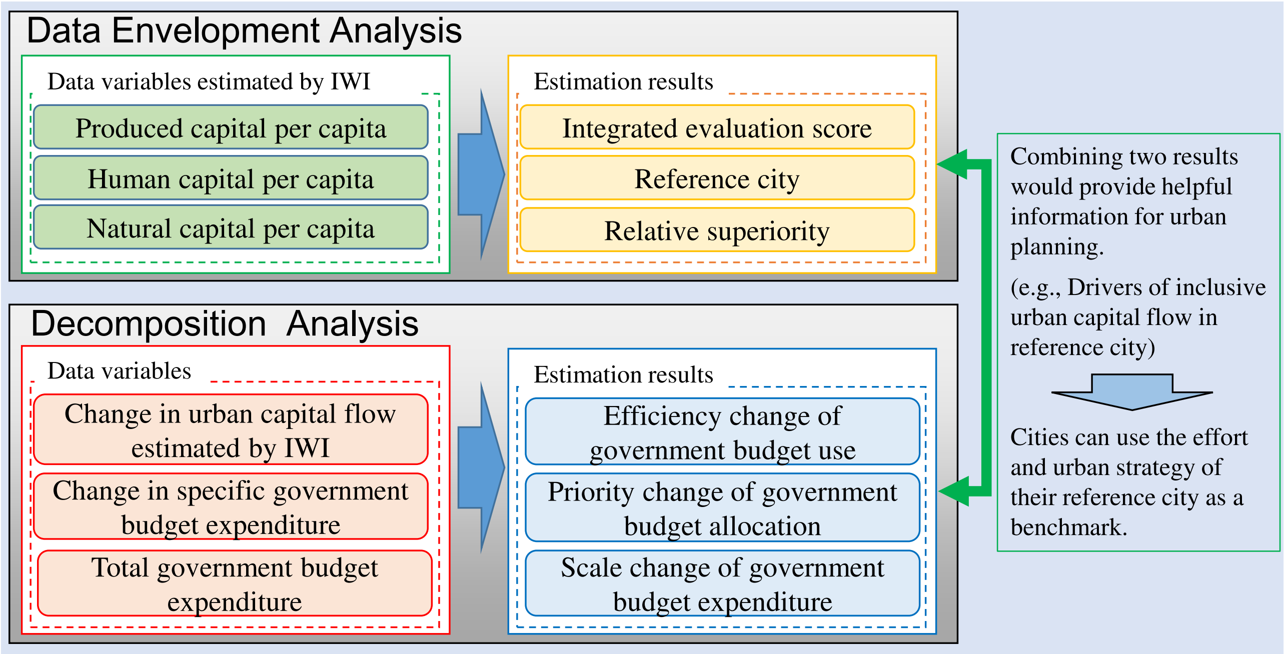

Figure 1. Diagram outlining the approaches in this study

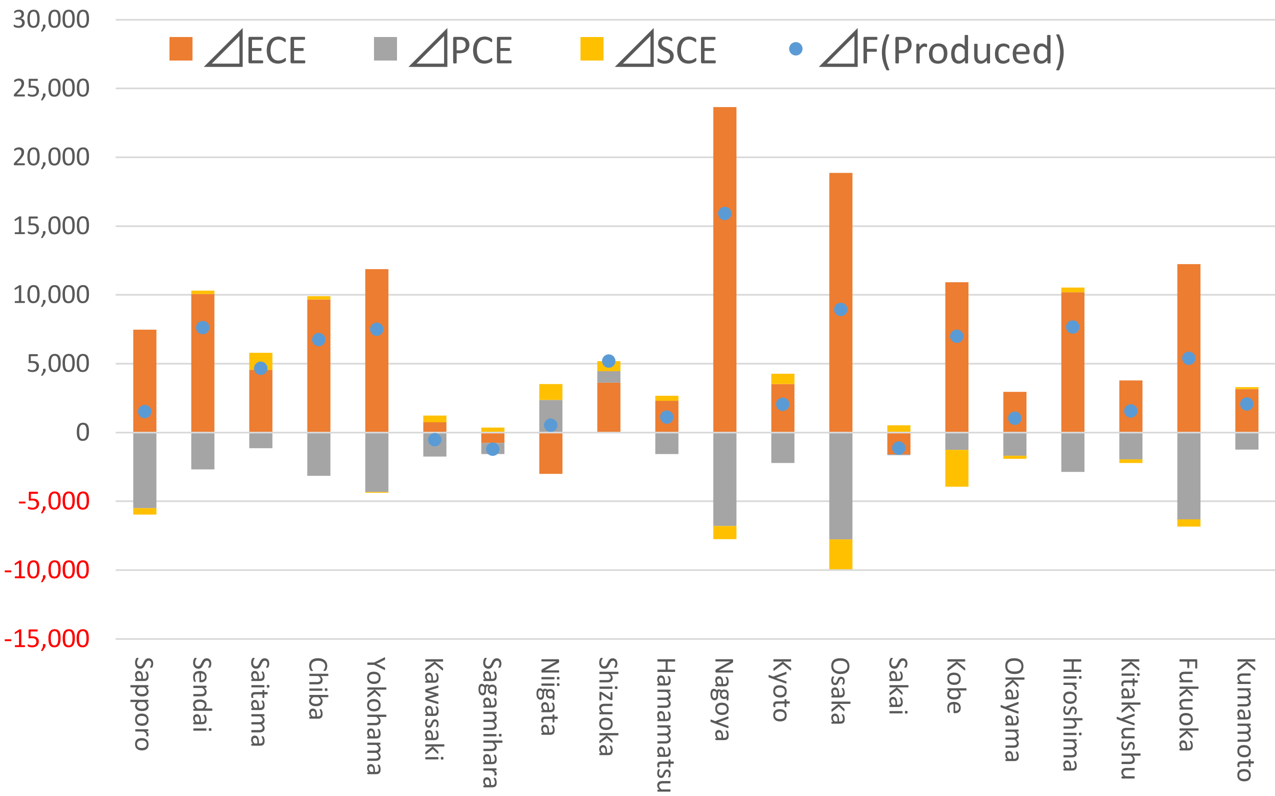

Figure 2. Decomposition analysis of changes in produced capital stock (100 million yen)

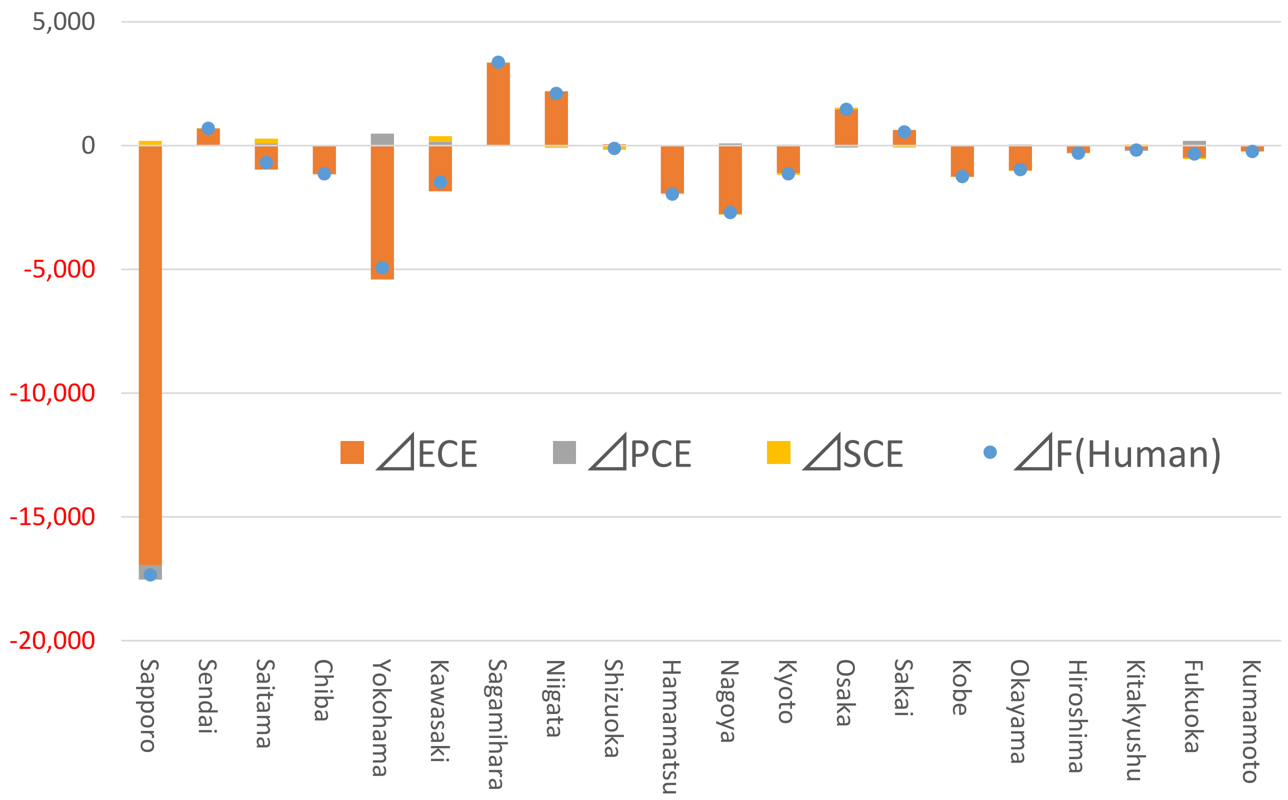

Figure 3. Decomposition analysis of changes in human capital stock (100 million yen)

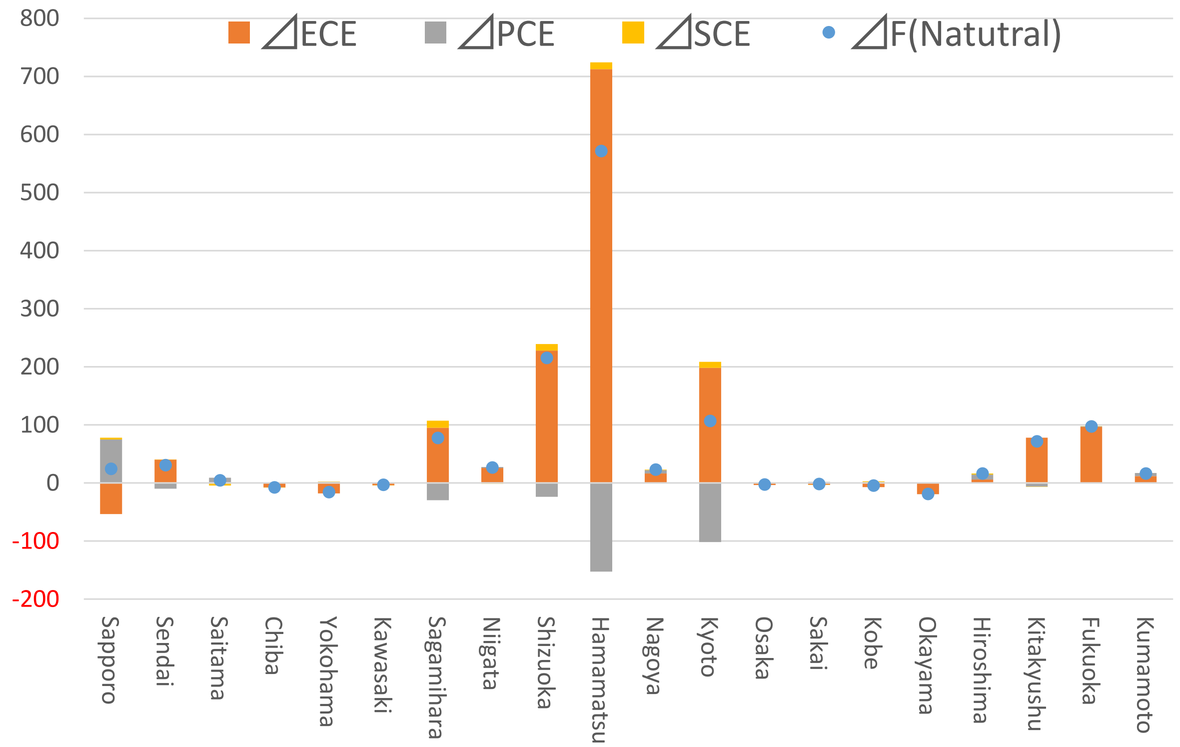

Figure 4. Decomposition analysis of the changes in natural capital stock (100 million yen)

Appendix. Grouping of local government budget expenditures

Government budget expenditure category	Grouping in this study
Civil engineering works (maintenance of civil engineering works, roads and bridges, rivers, stream and coasts, ports and harbors, city planning, dwellings, airports)	Expenditure for produced capital accumulation
Welfare (social welfare, welfare for the elderly, child welfare, livelihood protection, disaster relief)	Expenditure for human capital accumulation
Hygiene (public health, tuberculosis control, health centers, refuse disposal)	Expenditure for human capital accumulation
Education (educational administration, elementary schools, lower secondary schools, upper secondary schools, universities, social education, health and physical education)	Expenditure for human capital accumulation
Agriculture, forestry and fisheries (farming, raising livestock, agricultural land, forestry, fisheries)	Expenditure for natural capital accumulation