IMPROVEMENT OF INFRASTRUCTURE MAINTENANCE TECHNOLOGY AND GROWTH OF AGGREGATED ECONOMY

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ABSTRACT

Investment to infrastructure increases the needs of maintenance as well as accumulating the stock. Improvement of the management technologies regarding sensing, deterioration forecasting and asset management reduce the cost of maintenance. Therefore the improvement of infrastructure maintenance technology will increase the share of other expenditure. It contributes to higher level of utility of aggregated economy from a point of view of macroeconomics.

Asset management of infrastructure stock, in general, aims to minimize life cycle cost of maintenance of an asset. However, this paper focuses on the macroeconomic effect of the maintenance technology. This paper develops an economic growth model where infrastructure maintenance technology explicitly influences to deterioration of infrastructure stock. Expenditure share of investment (private capital and infrastructure respectively), consumption and maintenance is controlled to achieve optimal growth path. The numerical analyses derive some implications about the relationship between the technological improvement of infrastructure maintenance and growth rate of the economy. Optimal fiscal policy with regard to allocation between investment to new infrastructure and maintenance expenditure for existing infrastructure is also analyzed.

Keywords: Infrastructure Maintenance, Economic Growth, Deterioration Control

INTRODUCTION

In developed countries, cost of infrastructure maintenance, replace and disposal will increase in the near future. Japanese Government states the importance of the strategic maintenance of infrastructure (Ministry of Land Infrastructure and Transport (2003)). Maintenance engineering technologies such as sensing, deterioration forecasting and asset management technology have been improving. However, macroscopic infrastructure management system, namely concept of budget allocation regarding infrastructure in a city/municipal or in a nation, is relatively less developed.

Relationship between public investment and economic growth is one of the important research fields in macroeconomics. Most of the Literatures on the endogenous growth emphasized the contribution of public investment to long run growth. Recently, the efficiency of public investment and maintenance expenditure for public capital is emerging as an important issue. This article builds the simple dynamics economic model which treats deterioration control by the infrastructure maintenance explicitly. Furthermore, the influence to optimal infrastructure investment and maintenance policy by the change of maintenance technology is analyzed by the numerical simulation.

LITERATURE REVIEW

Infrastructure is usually defined as a capital stock invested by public sector in the economic models. The framework of the analysis of the relationship between economic growth and public capital investment by growth model was established by Arrow and Kurz (1970). Arrow and Kurz (1970) built a growth model which regards public capital as an input factor of production function, and analyzed optimal public investment policy. This approach was succeeded in Barro (1990) and King and Rebelo (1990) and the modelling has been refined. Optimal size of the government and taxation system are discussed in Barro (1990) from a point of view of endogenous growth theory. King and Rebelo (1990) analyzes optimal tax policy by using a human capital-driven endogenous growth model. The principal issue of these earlier works was fiscal policy or tax policy, and they didn't mention about infrastructure policy.

Physical infrastructure stock such as road, airport and container port has a capacity. Therefore congestion externality occurs when the demand approaches the upper limit of the capacity. This physical aspect was introduced to growth model and fiscal policy concerning infrastructure investment was argued in Glomm and Ravikumar (1994). Elimination of the assumption of non-rivalness for public capital was one of the main improvements of theoretical modelling. On the other hand, empirical studies of the productivity of infrastructure emerged after Aschauer (1989). The question how Infrastructure investment contributes to economic growth was tested by the stream of the empirical researches. An interesting result that non-investment expenditure such as maintenance contributes to economic growth more than investment to capital in developing countries was examined by Devarajan et al (1996). The empirical study of Latin American countries by Rioja (2003) also supported the conclusion of Devarajan et al (1996).

Rioja (2003) built a macroeconomic growth model with explicit infrastructure maintenance in order to implement the empirical analysis. Depreciation of infrastructure stock depends on governments' maintenance expenditure, namely endogenously determined, in Riojas' model. Rioja (2003) assumes that investment to public capital is fully financed by foreign aid, and therefore budget allocation among investment and maintenance by the government was out of scope.

The optimal allocation issue was analyzed in Kalaitzidakis and Kalyvitis (2004). Kuwajima and Otazawa (2006) and Dioikitopoulos and Kalyvitis (2008) deal with not only maintenance but also congestion aspects as well as Glomm and Ravikumar (1994) in endogenous growth model. The theoretical framework of the growth models have developed by these researches. However, most studies discuss only financial issue or tax policy issue and do not mention the influence by change of infrastructure management technology.

Infrastructure engineering technology is interpreted as efficiency of investment and deterioration control in the recent growth model by Ueda and Yokomatsu (2006), Ishikura (2007) and Ochi et al. (2008). Understanding the contribution of the engineering technology is important for research and development policy of the technology as well as infrastructure related budget allocation. Although the previous studies analyze the relationship between the engineering technology and growth conceptually, estimation of quantitative effect is required for practical implication. This paper emphasizes simulating methodology of the growth model with infrastructure deterioration control by stock maintenance, and examines several numerical analyses.

THE MODEL

Here we set up an optimal growth model with infrastructure investment and infrastructure maintenance. We assume a closed economy where a representative household maximizes the utility over time. There are three production input factor, labor, private capital stock and infrastructure stock. The endowment and growth rate of labor are exogenously given. Private capital is accumulated only by private investment and depreciates with a constant rate. Infrastructure stock is also accumulated by public investment as well as private capital.

However we assume deprecation rate of infrastructure stock is not constant, because the maintenance prevents infrastructure stock from deterioration. Deterioration rate, which is assumed to be equivalent to depreciation rate in this paper, depends on maintenance expenditure and the amount of existing infrastructure stock. If the ratio of maintenance expenditure to the stock is small, deterioration is accelerated. Allocation of production income to consumption, private investment, infrastructure investment and infrastructure maintenance is controlled to achieve social optimum growth path.

We assume the standard constant intertemporal elasticity of substitution type utility function.

$$u\left(C_t\right)=\frac{C_t^{1-\sigma}-1}{1-\sigma} \tag{1}$$

Where C_t denotes consumption at time t, σ denotes parameter regarding substitution and u is utility. Production technology of the economy is assumed to be Cobb-Douglas function. Let Y_t, K_{Gt}, K_t and L_t denote Output, Infrastructure stock, private capital stock and labor at t respectively. Production function is represented as follows.

$$Y_t = A\cdot\left(K_{Gt}\right)^{\theta}\left(K_t\right)^{\alpha}\left(L_t\right)^{1-\alpha} \tag{2}$$

Market clearing condition should be kept at every time t. Income flow should fully allocate to consumption C_t, private investment I_t, infrastructure investment IG_t and maintenance expenditure M_t.

$$Y_t = C_t + I_t + I_{Gt} + M_t \tag{3}$$

The accumulation of private capital stock and infrastructure stock are formulated as the two state equations.

$$K_{t+1} - K_t = I_t - \delta K_t \tag{4}$$

$$K_{Gt+1} = I_{Gt} + K_{Gt}\left(\frac{M_t}{K_{Gt}}\right)^{\gamma} \tag{5}$$

Where δ denotes depreciation rate of private capital and γ denotes a parameter concerning maintenance technology.

Representative household maximizes utility by choosing optimal stream of the flow such as consumption and investment. The dynamic utility maximization is formulated as the following infinite horizon optimization problem.

$$\max_{\{C_t\}_0^\infty} V = \sum_{t=0}^{\infty}\beta^t u_t\left(C_t\right) \tag{6}$$

s.t.
(1), (2), (3), (4) and (5).

Where β denotes discount factor. To utilize dynamic programming, the Bellman Equation of this problem is written as follows.

$$V\left(K, K_G\right) = \max_{C,I,M,I_G}\left[\frac{C^{1-\sigma}-1}{1-\sigma} + \beta V\left(K', K_G{}'\right)\right] \tag{7}$$

The script of time t is dropped, therefore state equation is redefined.

$$K' = I_t + \left(1-\delta\right)K \tag{8}$$

$$K_G{}' = I_G + K_G\left(\frac{M}{K_G}\right)^{\gamma} \tag{9}$$

NUMERICAL SIMULATION ANALYSIS

Setup and Base Case Results

In this chapter we examine how the optimal policy is affected by the exogenous change of infrastructure maintenance technology. Firstly, the model parameters and the value of state variables in the base case are set up to get a reasonable growth path (see Table I). Then we apply Value Function Iteration to obtain policy function of the model.

Table I – Parameters in the Base Case of the Numerical Simulation

Parameter	Value
α	0.4
β	0.95
δ	0.05
θ	0.2
σ	1.1
γ	0.15
A	1
K	240~360
K_g	80~120
L	100

Figure 1, Figure 2 and Figure 3 represent the policy function of infrastructure investment, maintenance expenditure and private investment respectively, which are results of the base case simulation. As shown in Figure 1 and Figure 2, accumulation of infrastructure stock makes infrastructure investment decrease. It means the investment and the maintenance are substitutive relationship. When the level of infrastructure stock is high, maintenance is relatively more efficient. The characteristic is consistent with empirical results of Devarajan et al (1996).

Accumulation of private capital stock also lowers the marginal productivity of the capital and decrease the flow of private investment. When the level of private capital stock is small, the increase of infrastructure stock stimulates private investment (see Figure 3).

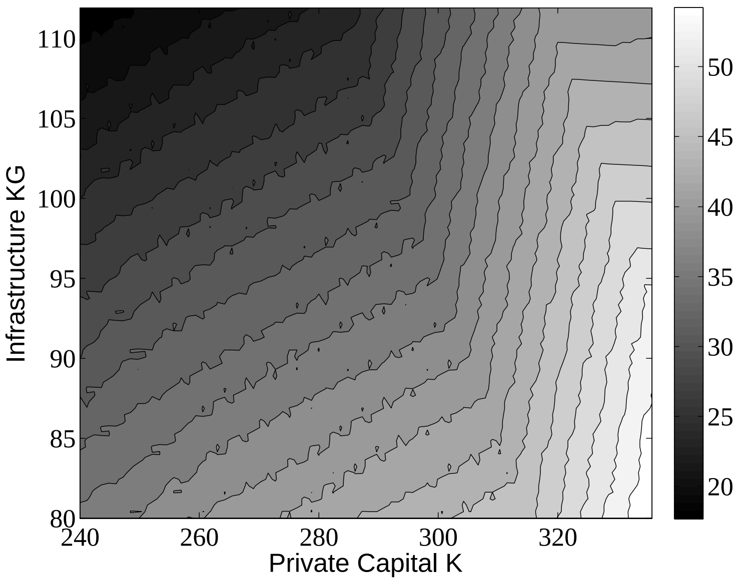

Figure 1 – Mapping of Optimal Infrastructure Investment I_G in the Base Case

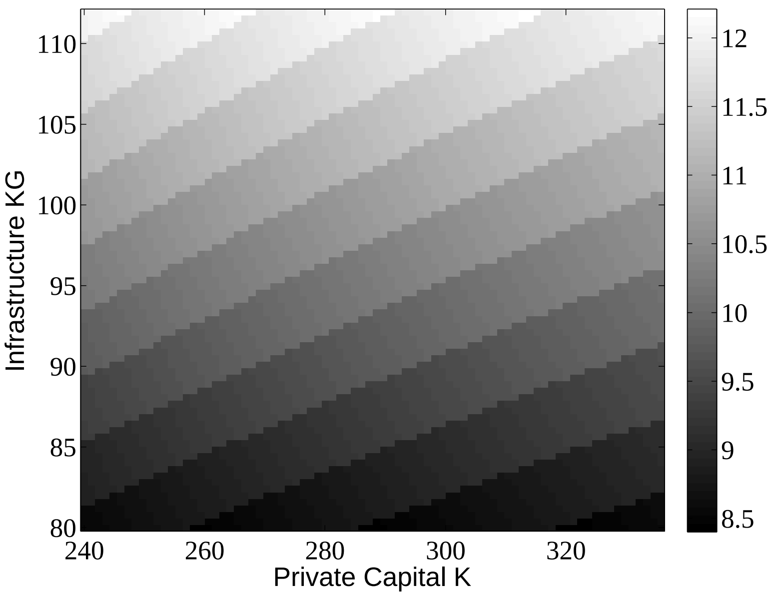

Figure 2 – Mapping of Optimal Maintenance Expenditure M in the Base Case

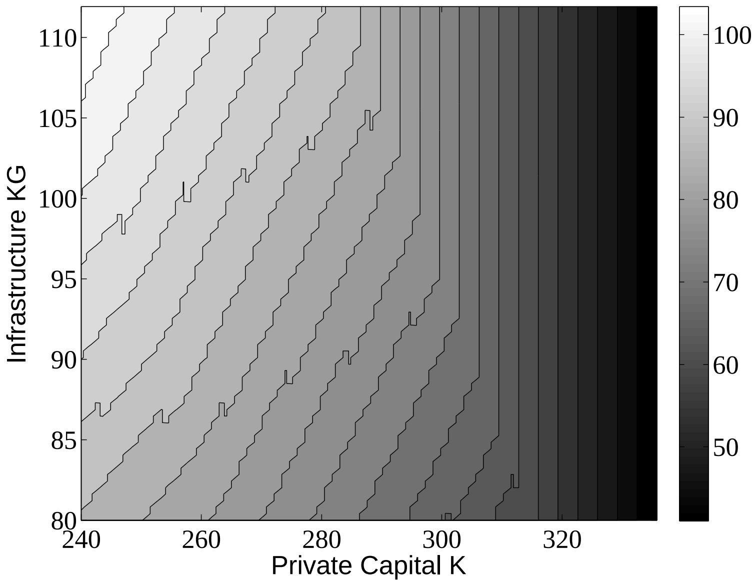

Figure 3 – Mapping of Optimal Private Investment I in the Base Case

Effects by Technological Change of Infrastructure Maintenance

Parameter γ concerns the level of infrastructure maintenance technology. If γ is higher value, preventing the deterioration of infrastructure stock requires much maintenance expenditure. Therefore the lower value of parameter g means the higher technology of the maintenance engineering.

The numerical simulation is able to obtain the policy function of every flow variables (C, I, I_G, M) and optimal dynamics of the state variables for any states of infrastructure stock and private capital stock. This section emphasizes only the behavior of the dynamics of infrastructure stock, because we are interested in infrastructure policy. Figure 4, Figure 5 and Figure 6 represent the Contour of Optimal K_G at next period and vector field of dynamics of K_G and K for each state of the stocks in Base Case, More Efficient Maintenance Technology Case and Less Efficient Maintenance Technology Case respectively.

When the efficiency of maintenance technology is lower level, the optimal level of the infrastructure is also lower. In other words, lower efficiency technology needs much maintenance expenditure then other expenditure flow such as consumption must be reduced. Therefore optimal variation of the infrastructure is lower when the efficiency of maintenance technology is poor. The variation of infrastructure might be negative in case of the lower level of private capital stock. The results also demonstrate that this analysis method is able to estimate how much technological improvement of infrastructure maintenance accelerates the accumulation of infrastructure stock, say economic growth.

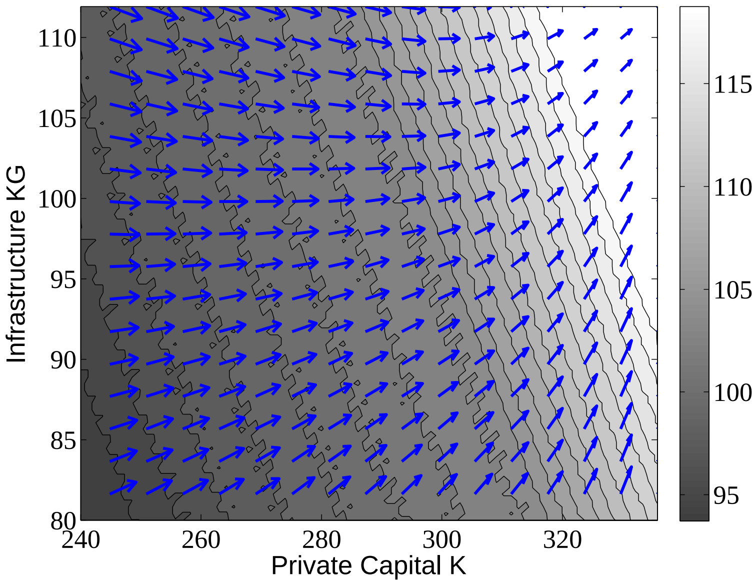

Figure 4 – Contour of Optimal K_G at Next Period and Vector Field of Dynamics of K_G and K in the Base Case (γ=0.15, θ=0.2)

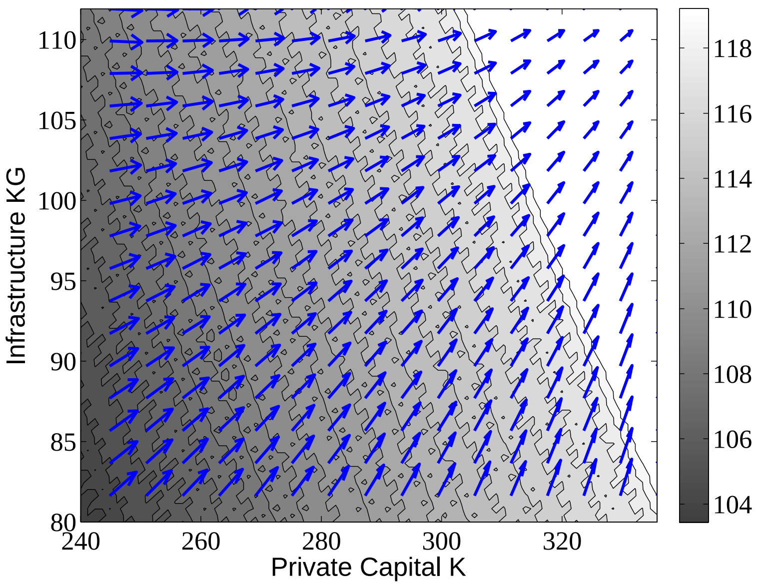

Figure 5 – Contour of Optimal K_G at Next Period and Vector Field of Dynamics of K_G and K in the More Efficient Maintenance Technology Case (γ=0.1, θ=0.2)

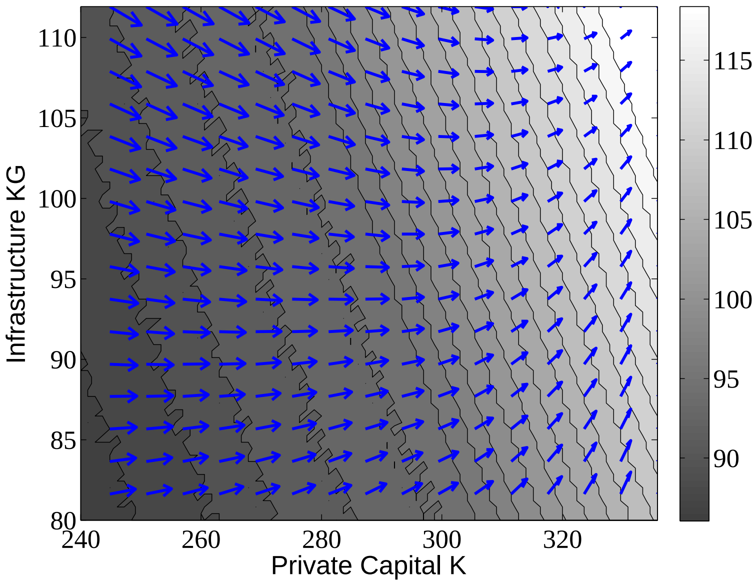

Figure 6 – Contour of Optimal K_G at Next Period and Vector Field of Dynamics of K_G and K in the Less Efficient Maintenance Technology Case (γ=0.2, θ=0.2)

Effects by Exogenous Change of Productivity of Infrastructure Stock

The improvement of infrastructure engineering technology also improves the productivity of the infrastructure stock itself. For example, modernization and energy saving technology of infrastructure stock can reduce the input cost of production. The second simulation analysis examines the impacts by change of productivity of infrastructure stock. The simulation results of the lower productivity case and it of the higher productivity case are shown in Figure 7 and Figure 8 respectively. The output index is similar to the previous analysis.

The results imply that the productivity of infrastructure influences to the dynamics of infrastructure itself sensitively, especially when the level of private capital is low. Qualitative development of infrastructure as an input factor of production is one of the crucial engine of the economic growth.

The drastic change of the shape of policy function with regard to flow variables is not observed between the cases. The main difference is the level of value, not the shape. Our simulation analysis assumes a virtual economy, and the parameters are also not based on real economy. Practical application of the model needs the econometric identification of the parameters and function form. However it is difficult to know the function of infrastructure maintenance technology from a macroeconomic viewpoint. Therefore sensitive analysis and numerical simulation implemented by this paper can be a useful method to understand scope of possible economic path. This simulation analysis provides a guideline of procedure of the model application rather than actual political implication.

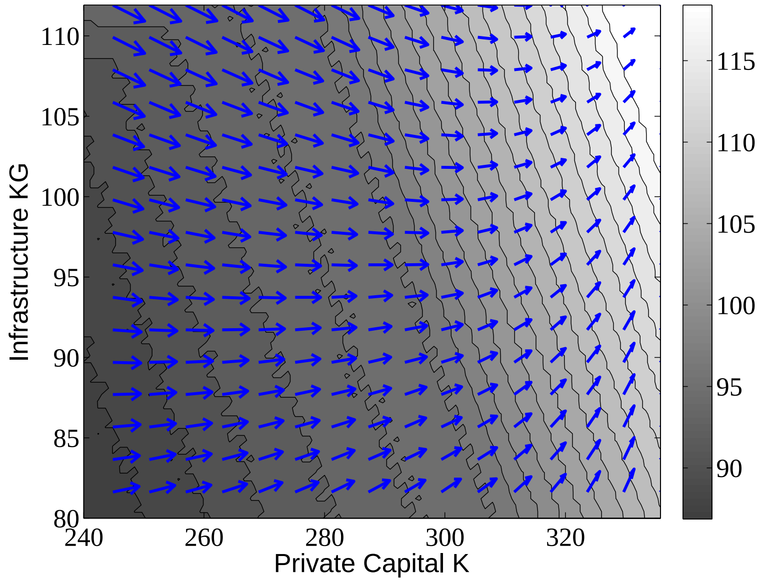

Figure 7 – Contour of Optimal K_G at Next Period and Vector Field of Dynamics of K_G and K in the Lower Productivity of Infrastructure Stock Case (γ=0.15, θ=0.19)

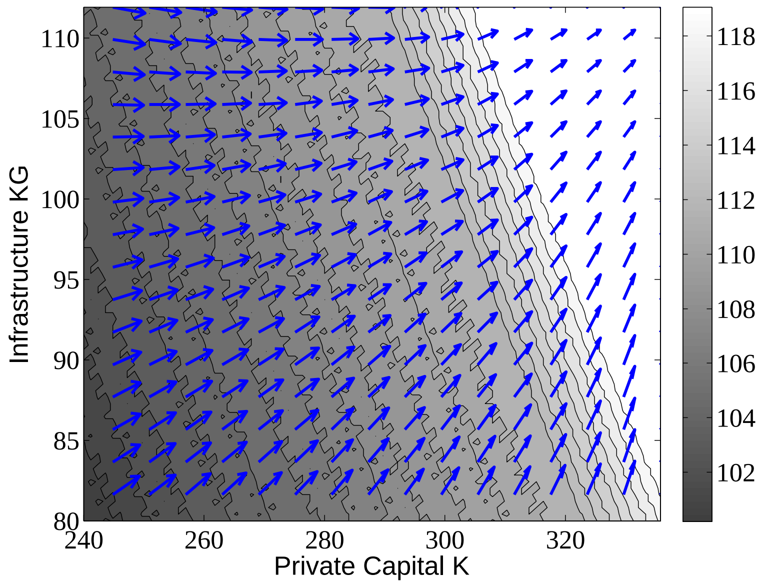

Figure 8 – Contour of Optimal K_G at Next Period and Vector Field of Dynamics of K_G and K in the Higher Productivity of Infrastructure Stock Case (γ=0.15, θ=0.21)

CONCLUDING REMARKS

This paper develops an economic growth model where infrastructure maintenance technology explicitly influences to deterioration of infrastructure stock. Expenditure share of investment (private capital and infrastructure respectively), consumption and maintenance is controlled to achieve optimal growth path in the model. The numerical analyses derive some implications about the relationship between the technological improvement of infrastructure maintenance and productivity of infrastructure and stock accumulation path of the economy. Qualitative aspects of our results are consistent with the earlier theoretical works in macroeconomic research field, and we add furthermore quantitative implications about economic dynamics. Integrating the knowledge about infrastructure engineering technology and this economic simulation methodology will create more fruitful policy planning tool. Investigation of the macroscopic effects of maintenance technology and brushing up the formulation are the future task of this field.

This research was funded by a grant from JSPS (Japan Society for the Promotion of Science) Global COE (Center of Excellence) program entitled "Global Center for Sustainable Urban Regeneration"

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