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Importance of a Victim-Oriented Recovery Policy after Major Disasters

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Abstract

This paper employs a growth model with public infrastructure, which is included in both utility and production functions, and investigates the importance of a victim-oriented recovery policy after major natural disasters such as the 2011 Great East Japan Earthquake and Tsunami. More concretely, the role of deep parameters in the recovery process is closely examined. Through the analysis, we find that the magnitude of public concerns about infrastructure and the magnitude of the intertemporal elasticity of substitution substantially affect the progress of recovery. In terms of economic recovery in general, production activities tend to be emphasized, but our results imply that one should not disregard victim-oriented recovery.

JEL classification numbers: E61; H54; O41

Keywords: 2011 Great East Japan Earthquake and Tsunami;
Victim-oriented recovery policy; Speed of convergence; Public infrastructure

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1. Introduction

This paper investigates the long-term impacts of the 2011 Great East Japan Earthquake and Tsunami (hereinafter, GEJET) using a simple growth model with public infrastructure as stocks and some sorts of external effects. More specifically, the effects of a major disaster on various economic aspects, including the length of the recovery period, are closely examined.

The GEJET caused widespread human and physical damage, resulting in significant negative economic and social impacts. The extent of such damage definitely influences the length of the recovery period. In the model of this paper, we assume that the simulated value for the length of the post-disaster transition period corresponds to the length of the recovery process in actuality. Accordingly, by comparing the results in this paper with the actual recovery status, we are able to evaluate the overall recovery levels achieved at each stage and depict the long-term perspectives for the affected area.

As is well known, there are substantial theoretical and empirical studies employing a convergence approach for economic growth models. For example, Barro and Sala-i-Martin (1992), Mankiw et al. (1992), Barro et al. (1995), Caselli et al. (1996), Ortigueira and Santos (1997), and Islam (2003) are representative contributions. Much economic analysis treating natural disasters has been carried out with a central focus on empirical studies in affected areas (Naoi et al. 2012; Strobl, 2012; Barone and Mocetti, 2014). Skidmore and Toya (2002), Toya and Skidmore (2007), and Loayza et al. (2012) are examples of comprehensive empirical works using cross-country datasets. In particular, Loayza et al. (2012) employed system generalized method of moments estimators to confirm heterogeneous impacts due to disasters depending on the type and size of the disaster and the socioeconomic status of the affected country. However, few studies have attempted to apply a convergence approach that enables long-term analysis in disaster research. This is the main aim of the present paper. See Hosoya (2015) for a review of the recent literature on disaster research.

Now we briefly explain the traits of the model developed in this paper. The underlying model is an extended version of Hosoya (2015). The specifications for the production sector and the accumulation mechanism of infrastructure capital are exactly the same. A new characteristic of the present model is that we allow infrastructure levels for the utility function coupled with consumption.¹ This new extensional attempt is considered to be entirely valid, as it embraces victims preferences in emergency situations. After experiencing a major disaster, public concerns about public sector activities, including infrastructure provision, usually seem to increase. In any case, infrastructure is viewed as having a vital role in the present study.

¹The stock of infrastructure has a positive influence on activities related to the production of goods. This is an extremely general observation in the literature on growth theory, including that on endogenous growth models (e.g., Futagami et al., 1993; Agénor, 2010).

After presenting a theoretical solution, we conduct a numerical simulation using the model. First, we test a benchmark model, which excludes capital damages, and confirm the convergence property of this model. While doing so, we allow capital damages for numerical simulations by consulting precise estimates of actual capital destruction by the GEJET. Since there are large variations in capital destruction depending on the targeted area, we present various possibilities. Here, for a given level of capital destruction, the time between destruction and recovery to a specified level can be calculated in addition to other economic indicators, including the speed of convergence, making it possible to obtain long-term outlooks for recovery. We then compare the models with and without infrastructure levels in the utility function to examine quantitatively the effect of public concerns about infrastructure on the convergence rate and the recovery period. If the concerns have an obvious effect on economic performance, that provides a valuable viewpoint from which to consider the modality of recovery policy. Finally, we further examine the role of deep parameters in this issue. Namely, changing combinations of intertemporal elasticity of substitution and public concerns about infrastructure clarifies their impacts on the economy. If their role is indispensable in the recovery process, that would imply the significance of victim-oriented recovery policies.

The rest of this paper is organized as follows: Section 2 presents a basic framework and derives a theoretical speed of convergence. In addition, the properties of the dynamical system are clarified. Section 3 develops extensive numerical analyses regarding the recovery process from the GEJET and attempts to derive useful implications. In Section 4, we provide concluding remarks.

2. The model

2.1. Basic framework

The basic structure of the present model is identical with that in Hosoya (2015), except for the specification of the utility function. We present our dynamic optimization problem as follows:

$$\max_{C(t)} \int_0^{+\infty} \frac{(C(t)H(t)^\sigma)^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt, \quad \sigma \geq 0, \theta > 0, \theta \neq 1, \rho > 0, \quad (1)$$

subject to

$$\dot{K}(t) = (1-\tau)K(t)^\alpha H(t)^{1-\alpha} - C(t), \quad \tau \in (0, 1), \alpha \in (0, 1), K(0) = K_0 > 0 \quad (2)$$

Here, σ is the weight of public infrastructure, $H(t)$, in the utility function; θ is the inverse of the intertemporal elasticity of substitution; and ρ is the subjective discount rate. In the following, we omit the time argument t for simplicity of notation.

The lifetime utility function we should maximize is represented as (1). Raurich (2003) and Agénor (2011, 2013) employ similar specifications with respect to utility. A representative household enjoys satisfaction from the level of public infrastructure and from consumption, $C(t)$. Households *cannot* be directly involved with the public provision of infrastructure, but they *can* draw satisfaction from the infrastructure level provided by their taxes. For example, a person who lives beside a river would enjoy the feeling of safety from the constructed riverbanks.

Next, we briefly explain the goods production sector. Two production inputs are physical capital K and an efficient labor HL . Namely, the infrastructure level affects labor productivity. Assuming the total labor force is constant and unity ($L = 1$), the output Y is produced by the following Cobb–Douglas technology: $Y = K^\alpha H^{1-\alpha}$. This is a standard specification in the literature on endogenous growth. Government expenditure on public infrastructure G is financed by a flat-rate income tax τ imposed on the representative household: $G = \tau Y$. Moreover, the law of motion of physical capital \dot{K} follows the standard process, $\dot{K} = Y - C - G$. As a result, the representative household faces the constraint of (2).

Note that in the decentralized economy, H is an exogenous variable, and so the household maximizes its own utility ignoring the exogenously given public infrastructure.²

Now, we employ the following assumption:

Assumption 1. Independent of the joint concavity condition on the utility function (see footnote 2), we assume $\theta \geq \sigma/1 + \sigma$ for analytical simplicity.

As shown below, this assumption guarantees the uniqueness of the steady-state equilibrium. Our focus is on speed of convergence to any long-term equilibrium, so this uniqueness property is favorable. As is well known, assumptions on deep parameters are crucially important in studies of macroeconomic dynamics. Regarding the size of intertemporal elasticity of substitution, a diverse range of estimates has been obtained in various empirical studies (see, for example, Hansen et al., 2007). In particular, a relatively low degree of intertemporal substitutability in consumption, which typically ranges between one half and two, would establish plausibility.³ From these findings, $\theta \geq \sigma/1 + \sigma$ is a reasonable assumption.

We solve the corresponding dynamic optimization problem by applying the maximum principle, obtaining

$$g_C = \frac{1}{\theta} \left(\alpha(1 - \tau) \left(\frac{K}{H} \right)^{\alpha-1} + \sigma(1 - \theta)g_H - \rho \right), \quad (3)$$

²For this reason, no joint concavity condition imposed on C and H (i.e., $\theta \geq \sigma/1 + \sigma$) is needed in the present case.

³Note that in our notation $1/\theta$ corresponds to the parameter.

where g_x denotes the equilibrium growth rate for x . A derivation for (3) is given in Appendix A.

The structure of the accumulation of public infrastructure follows Hosoya (2014, 2015). Government expenditure for infrastructure G , which is financed by a proportional income tax, and capital deepening external effects S , which influences its expenditure efficiency, characterize the accumulation process of infrastructure. We can therefore specify $\dot{H} = \delta GS$, where δ is a positive constant. The external effects are defined by the ratio of private capital to public infrastructure, which can capture overall living standards in a general context. Allowing for $G = \tau Y$ and $S = (K/H)^\epsilon$ in the above equation, one obtains $K/H = (g_H/\delta\tau)^{1/(\alpha+\epsilon)}$, where the parameter ϵ stands for the degree of externality.⁴ Finally, applying the balanced growth path (BGP) relation $g \equiv g_Y = g_C = g_K = g_H$ to (3), we obtain

$$g = \frac{1}{\theta} \left(\alpha(1-\tau) \left(\frac{g}{\delta\tau} \right)^{\frac{\alpha-1}{\alpha+\epsilon}} + \sigma(1-\theta)g - \rho \right). \quad (4)$$

From (4), we find that the equilibrium growth rate g at the BGP depends on the parameters $\{\alpha, \tau, \delta, \epsilon, \sigma, \rho, \theta\}$. In addition, the following holds:

Proposition 1 (Existence and uniqueness) *Under the assumption for deep parameters, that is, $\theta \geq \sigma/(1+\sigma)$, there exists a unique equilibrium with a positive solution of g .* \square

Proof : From (4), $(\theta - \sigma(1-\theta))g + \rho = \alpha(1-\tau)(g/\delta\tau)^{(\alpha-1)/(\alpha+\epsilon)}$ is obtained. Now we define the left-hand side of this equation by $\Psi(g)$, and the right-hand side by $\Gamma(g)$. First, under the assumption of $\theta \geq \sigma/(1+\sigma)$, Ψ is represented by a linear function of g with a positive or zero slope in the first quadrant of the (g, Ψ) -plane. Second, we find that $\Gamma(g)$ is a strictly decreasing and strictly convex function of g in the same quadrant, in view of the functional properties $\lim_{g \rightarrow 0} \Gamma(g) = +\infty$, $\lim_{g \rightarrow 0} \Gamma'(g) = -\infty$, $\lim_{g \rightarrow +\infty} \Gamma(g) = 0$, and $\lim_{g \rightarrow +\infty} \Gamma'(g) = 0$. Due to these functional properties, the equilibrium at the BGP is uniquely determined. \blacksquare

Moreover, on the stability property of the model, we can state the following proposition.

Proposition 2 (Local stability) *The unique equilibrium under the corresponding dynamical system is locally saddle-path stable.* \square

Proof : See Appendix B. \blacksquare

2.2. Speed of convergence

⁴For further details, see Hosoya (2014, 2015).

In common with Hosoya (2015), which develops the baseline model of this paper, the original three-dimensional dynamical system on (C, K, H) can be transformed by two new variables, a control-like variable $X \equiv C/K$ and a state-like variable $Z \equiv K/H$. As a result, the following holds:

$$\frac{\dot{X}}{X} = X + \left(\frac{1-\theta}{\theta} \right) \delta \sigma \tau Z^{\alpha+\epsilon} + \left(\frac{\alpha-\theta}{\theta} \right) (1-\tau) Z^{\alpha-1} - \frac{\rho}{\theta}, \quad (5)$$

$$\frac{\dot{Z}}{Z} = -X + (1-\tau) Z^{\alpha-1} - \delta \tau Z^{\alpha+\epsilon}, \quad (6)$$

where (6) is identical with (11) in Hosoya (2015). This two-dimensional system characterizes the dynamics of the model.

Log-linearizing (5) and (6) around the BGP, we obtain a characteristic polynomial that contains a negative (stable) root λ_1 (see Appendix C for a detailed derivation). The root is given by

$$\lambda_1 = \frac{(X^* - V_1 - V_2) - \left[(V_1 + V_2 - X^*)^2 + 4 \left(\frac{\alpha}{\theta} V_1 + \left(\frac{\theta - \sigma(1-\theta)}{\theta} \right) V_2 \right) X^* \right]^{1/2}}{2}. \quad (7)$$

Here, we denote $\tilde{\lambda}$ as $\tilde{\lambda} = -\lambda_1$. As a result, the speed of convergence (i.e., the convergence coefficient) for the present model is given by $\tilde{\lambda}$. Appendix D briefly shows the numerical algorithm for obtaining λ_1 . The convergence rate $\tilde{\lambda}$ characterizes the overall transition process of the economy. As is well known, the $100 \times \beta\%$ of the adjustment (transition) time from the initial point to a long-run steady state is given by $T(\beta) = \ln(1-\beta)/\lambda_1$. For example, if $\beta = 0.5$ (i.e., 50%) and $\lambda_1 = -0.069$, the time needed to reach half of the total adjustment process is just 10 years.

2.3. Premises for numerical simulations

The following are used as premises for numerical study of the recovery process from the GEJET, as also posited in Hosoya (2015):

(i) The present speed of convergence is derived by the linear approximation method, so the calculated $\tilde{\lambda}$ is valid as only an approximate value in the neighborhood of the BGP equilibrium. As will be introduced in a later section, the estimates for the rate of capital destruction are relatively *small* (about 10–20% on average), contrary to what we expected from our field observations, even when limiting the target to the disaster-affected area. That is, if the economy was located in a steady state at the instant of the GEJET, it seems that divergence from the equilibrium is not wide. Also, the speed of convergence in the present model is relatively *fast* as compared with that predicted by typical neo-classical growth models. Thus, our focus on the neighborhood of the long-term equilibrium is reasonable. Overall, the linear approximation method, which is

advantageous for investigations in the vicinity of the steady state, seems to be a valid choice for the given analytical environment. Therefore, we can obtain insights about the process of economic recovery by observing variations in $\tilde{\lambda}$ after the occurrence of the GEJET.

(ii) As discussed in detail in Hosoya (2015), in the original context of growth theory, the rate of convergence implies that speed governs the transition from the old BGP (the initial point) to the new BGP. Thus, we make the following assumption for analytical purposes.

Assumption 2. The transition period as derived by the computed convergence coefficient approximately equals the period for recovery from the disaster.

Accordingly, the initial point of the recovery period corresponds to the time immediately after the disaster, while the terminal point is approximated theoretically as the time at which the overall recovery process is 99% complete.

(iii) The GEJET was an unprecedented catastrophe for the Japanese economy and society. If we focus on the damage to capital and infrastructure, however, the damage is concentrated along the Pacific coast of eastern Japan, shown in Figure 1. Hence, this area is appropriate as our unit of analysis. At a minimum, the following practical assumptions are required in order to attempt a reasonable analysis.

Assumption 3. The disaster area is a closed economy.

From Assumption 3, if inter-regional cooperation for recovery in the whole of Japan further strengthens, for example, then the various values computed in Section 3 may improve.

(iv) When damage rates are used in the numerical computation based on the model, we assume, for analytical convenience, that the damage is reflected in the ratio of K to H . The calculation method for a set of given damage estimates is shown in Appendix D. As is commonly known, the GEJET destroyed both private capital and public capital (infrastructure). In the present analysis, however, it would be difficult to adopt an individual damage rate for each type of capital. Instead, we tentatively focus on capital damages to infrastructure as characterized by K/H , and apply the estimated value to this ratio. For example, the amounts of K and H at the pre-disaster steady state were reduced by, respectively, 40% ($0.6K$) and 25% ($0.75H$) by the GEJET. Thus, we have $0.6K/0.75H = 0.8K/H$. In this case, 0.8 corresponds to ψ in Appendix D. Consequently, ψ describes the percentage of remaining capital. From estimates on the rate of capital destruction that will be introduced later, we suppose this to be a reasonable rate of remaining capital and adopt it as ψ . Various simulation studies are then developed.

3. Numerical analysis

3.1. Basic result

In this section, we explore various numerical computations based on (4)–(7). Table 1 shows the three results of computations as a benchmark.⁵

Table 1

Benchmark results.

	α	δ	ϵ	σ	X^*	Z^*	$\tilde{\lambda}$	g	$T(50\%)$	$T(90\%)$
(a)	0.35	0.2	0.4	0.5	0.223	8.553	0.088	0.02000	7.89	26.21
(b)	0.30	0.2	0.6	0.4	0.260	5.986	0.104	0.02001	6.69	22.22
(c)	0.30	0.5	0.1	0.7	0.270	5.689	0.091	0.02003	7.62	25.31

Note: Fixed parameters are $\rho = 0.05$, $\theta = 1.5$, and $\tau = 0.02$.

Note that in these first computations, we do not consider capital destruction by the GEJET. In the following, we take up case (a) in Table 1 for convenience.

Due to the values of X^* and Z^* , and the growth rate at the BGP, our benchmark computations are considered to be an accurate depiction judging from the existing growth studies. When fully examining the convergence rate and the transition periods, the present case is consistent with the ones in a model of endogenous growth, that is, the convergence of the present model is relatively fast.

The two rightmost columns of Table 1 gives estimates for reaching recovery levels 50% and 90%. A high convergence rate is reflected in these estimates, namely, our prospects are that half of the recovery does not require one decade, and the total process is completed within approximately one generation.

Now we re-compute case (a) in view of the capital damage due to the GEJET. Based on estimates by the Development Bank of Japan (DBJ), partially displayed in Figure 1, we vary the setting rates of damage from 10% to 50%.⁶ Our intended recovery levels are the four cases (20%, 50%, 80%, and 90%) displayed in Table 2 together with the other basic indicators. It is intriguing how differences in the recovery period show up according to variations of the destruction rate.

Table 2

Benchmark results at various destruction rates.

⁵For a detailed discussion on benchmark parameter values, except for σ , see Hosoya (2015).

⁶This estimate, released at a relatively early stage in the post-disaster period, estimated the percentage of capital destruction in detail on a regional basis. In Figure 1, we report only the damage rates of the coastal area in each prefecture. Dark areas in the figure represent municipalities that include areas inundated by the tsunami.

For (a):								
Destruction	X^*	Z^*	$\tilde{\lambda}$	g	$T(20\%)$	$T(50\%)$	$T(80\%)$	$T(90\%)$
10%	0.211	9.504	0.085	0.01597	2.62	8.15	18.92	27.07
20%	0.198	10.691	0.082	0.01174	2.71	8.41	19.53	27.94
30%	0.185	12.219	0.080	0.00725	2.79	8.66	20.11	28.77
40%	0.172	14.255	0.078	0.00243	2.86	8.88	20.61	29.49
50%	0.158	17.105	0.077	-0.00283	2.91	9.02	20.95	29.98

Note: $(\rho, \theta, \alpha, \tau, \delta, \epsilon, \sigma) = (0.05, 1.5, 0.35, 0.02, 0.2, 0.4, 0.5)$.

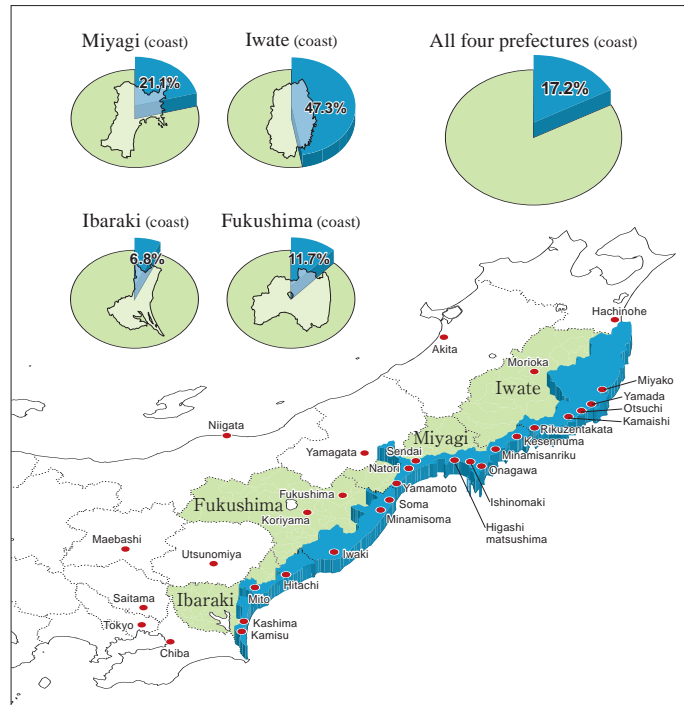


Figure 1: Overview of the disaster areas from the 2011 GEJET.

As seen in Figure 1, the damage estimates are quite different by area. For example, along the Pacific coast of Iwate prefecture, the most severely affected area, approximately half of the existing capital was destroyed. As noted before, this paper takes particular note of the Pacific coast of eastern Japan. More concretely, treating the Pacific coast of the Tohoku and northern Kanto regions as an integrated and analytically suitable unit, let us focus on the 10%- and 20%-destruction cases following the estimates by the DBJ. We consider *overall* recovery of this area to be *genuine* recovery.

First of all, we naturally find that the milder the capital damage, the shorter the recovery period. From Table 2, the recovery level as of June 2015 is predicted

to be approximately 30% of the overall process. In addition, based on the previous results that full recovery will require one generation, we estimate that it will take another 25 years from now until completion. As Hosoya (2015) points out, this estimate has a certain degree of relevancy, given other cases of recovery from World War II and major natural disasters.⁷ This can be viewed as a lengthy period, of course, but the positive view is that full recovery is possible in only one generation, which may be a relatively speedy recovery considering the extent of the damage. In either case, it is important to minimize the recovery period by combining various policies. This is one of the highest priority tasks for macroeconomic policy. We will revisit this issue in a later section.

On the surface, it is likely that differences in the damage rate have little impact on the length of the recovery period. As can be seen in the long-term values of X and Z , however, economic and social circumstances after project completion are quite different. In the case of severe damage, there is a need for investment to replace infrastructure while further reducing consumption; this is reflected in the results of Table 2. The more severe the damage, the lower the consumption–capital ratio X^* and the higher the capital–infrastructure ratio Z^* . This is interpreted as the economy attempting to restore private capital at the expense of daily life; the values of X^* and Z^* directly influence living standards, and thus are treated as vital variables. On the other hand, in the case of less severe damage the consumption–capital ratio is larger, through relatively rapid income (and thus consumption) growth.

3.2. Comparison with Hosoya (2015)

A crucial feature of the model is its specification of the utility function. We focus on the aspect that households are increasingly interested in the infrastructure environment as an important factor. This is naturally expected, as the importance of infrastructure is highlighted in post-disaster periods. As explained before, agents maximize utility at a given infrastructure level, so the level is external. This assumption is valid for the present situation, as this is a feature of disasters.

By introducing public infrastructure into the utility function, the idea noted above is obviously implemented to the model (see (1)). Hosoya (2015) employs a baseline model in which infrastructure level affects production activity only and provides important implications with respect to some post-disaster issues. Comparison with the previous and present models is an attempt to obtain further valuable implications for speeding the recovery process. In this section, we compare the numerical outcomes of the two slightly differing models under the same economic environment. For the parameter constellation, we follow Hosoya (2015).

Through changing the weighting parameter of infrastructure in the utility function, we confirm the responses of notable variables, including the speed of

⁷For details, see Davis and Weinstein (2002) and Jones (2014).

convergence, and discuss distinctions between the two models. Note that if the utility function has no infrastructure (as in Hosoya, 2015), it corresponds to the case of $\sigma = 0$ in this paper. In the following, the two scenarios (10% and 20% capital damage) are prepared with due considerations to the variation of estimates for the rate of capital destruction. Table 3 shows the case of 10% capital damage.

Table 3

The effect of public concerns about infrastructure on recovery status (1).

Model	σ	X^*	Z^*	$\tilde{\lambda}$	g	$T(50\%)$	$T(90\%)$
Hosoya (2015)	—	0.129	17.724	0.054	0.01754	12.73	42.30
This model	0.4	0.137	16.444	0.057	0.01655	12.18	40.46
This model	0.8	0.145	15.358	0.059	0.01566	11.69	38.83
This model	1.2	0.153	14.424	0.062	0.01485	11.25	37.36
This model	2.0	0.167	12.894	0.066	0.01343	10.49	34.83

Note: $(\rho, \theta, \alpha, \tau, \delta, \epsilon) = (0.025, 1.5, 0.35, 0.05, 0.1, 0.15)$. The rate of capital destruction is 10%.

Although each recovery period displayed in Table 3 is fairly different from those in Section 3.1 because we use a different set of parameters, the important point here is to observe the within variation of the results shown in Table 3. We clearly find that a high level of interest in public infrastructure, which is represented by a higher value of σ , contributes to reducing the recovery period. As compared with the standard case of $\sigma = 1.2$ and the case in which consumption alone constitutes the household's utility, the difference in the 90% recovery period between the cases is about 5 years, a significant difference.⁸ We then conducted the same computations with the estimate of damage to overall capital set as 20%. The results are shown in Table 4.

Table 4

The effect of public concerns about infrastructure on recovery status (2).

Model	σ	X^*	Z^*	$\tilde{\lambda}$	g	$T(50\%)$	$T(90\%)$
Hosoya (2015)	—	0.121	19.939	0.052	0.01502	13.28	44.13
This model	0.4	0.129	18.499	0.055	0.01374	12.72	42.24
This model	0.8	0.136	17.278	0.057	0.01257	12.21	40.55
This model	1.2	0.144	16.227	0.059	0.01150	11.75	39.04
This model	2.0	0.157	14.506	0.063	0.00960	10.96	36.42

⁸As mentioned before, Raurich (2003) uses a utility function similar to that the one in this paper. In reference to his numerical examples, $\sigma = 1.2$ is considered to be in the range of the adequate values.

Note: $(\rho, \theta, \alpha, \tau, \delta, \epsilon) = (0.025, 1.5, 0.35, 0.05, 0.1, 0.15)$. The rate of capital destruction is 20%.

Increasing the estimated initial damage ($10 \rightarrow 20\%$) naturally lengthens the transition (recovery) period. With respect to the scale of destruction, however, the added number of years is shorter than expected. Compared to the two cases of the presence or absence of public infrastructure in the utility (i.e., $\sigma = 1.2$ or 0), similarly to the 10% destruction case, the difference in the 90% recovery period is about 5 years, approximately the same result as in the previous scenario.

The results of this section reveal the meaning of our model considering the public's interest in public infrastructure. Whether we include the additional factor in the utility function considerably impacts the length of the recovery period. Regarding implications for recovery policy, the reconstruction of lost stocks in the recovery process tends to be top-down, but one should provide an infrastructure to meet the needs of affected people by employing bottom-up consultation. Doing so constructs truly valuable capital for the affected area. Creating suitable infrastructure while giving consideration to fiscal constraints substantially contributes to speeding recovery and shortening recovery period. From a qualitative respect, such a victim-oriented recovery policy has often arisen as a preferred topic in conversation. Regarding just this respect, our results provide intriguing implications, namely that public concern about infrastructure allows for a shorter period of recovery.

3.3. Deep parameters and recovery status

A final consideration of this paper is to examine the effects on convergence speed of a combination of θ , the (inverse of) intertemporal elasticity of substitution, and σ , which was explored in the previous section. Existing studies, including Ortigueira and Santos (1997), Hosoya (2015), and others have indicated the importance of intertemporal elasticity in convergence analysis, and have shown it to be an essential parameter in considering the nature of recovery from the GEJET. Moreover, from the aspect of model structure, the influences of these deep parameters are of particular interest. As clearly seen in (7), the product of θ and σ directly affects $\tilde{\lambda}$. It is important to grasp the extent to which this synergistic effect influences $\tilde{\lambda}$. For θ , we follow several existing studies and deal with three patterns: 1.5, 2.0, and 3.0.⁹ For σ , along with θ , three reasonable patterns (0.4, 1.2, and 2.0) are set, resulting in nine possible cases. The numerical results for each are shown in Table 5.

Table 5

Impact of deep parameters on recovery status.

⁹See, for instance, Ortigueira and Santos (1997), Alvarez-Albelo (1999), Eicher and Turnovsky (1999), Gokan (2003), Nakamoto (2009), Groth and Wendner (2014).

θ	σ	X^*	Z^*	$\tilde{\lambda}$	g	$T(50\%)$	$T(90\%)$
1.5	0.4	0.209	9.622	0.084	0.01624	8.22	27.31
	1.2	0.225	8.771	0.090	0.01426	7.71	25.60
	2.0	0.239	8.096	0.095	0.01259	7.29	24.20
2.0	0.4	0.234	8.252	0.079	0.01461	8.82	29.30
	1.2	0.260	7.189	0.086	0.01204	8.02	26.65
	2.0	0.282	6.425	0.093	0.01004	7.42	24.63
3.0	0.4	0.275	6.595	0.070	0.01249	9.84	32.69
	1.2	0.314	5.485	0.080	0.00968	8.67	28.82
	2.0	0.348	4.757	0.088	0.00764	7.86	26.11

Note: $(\rho, \alpha, \tau, \delta, \epsilon) = (0.05, 0.35, 0.02, 0.2, 0.4)$. The rate of capital destruction is 10%.

We find that a larger elasticity of substitution (i.e., a smaller θ) yields a faster convergence. This result is consistent with leading studies including Ortigueira and Santos (1997) and is considered as a fundamental feature of the literature.¹⁰ As confirmed in the previous section, a larger value of σ , which corresponds to the case where the agent benefits more from infrastructure levels, exhibits a faster transition process.

To give a quantitative implication, let us closely investigate the effect that the combination of these parameters has on the recovery period. For the less elastic case, the difference in the infrastructure weight strongly affects the variations in $\tilde{\lambda}$. From this, there are also measurable variations in the recovery period. For a 90% recovery level, the time intervals we obtained vary by more than a factor of two. More concretely, $\theta = 3.0$ leads to 6.58 years while $\theta = 1.5$ leads to 3.11 years. As is well known, the intertemporal elasticity corresponds to the coefficient of relative risk aversion. Thus the form of recovery policy including public infrastructure provision influences not only the supply side but also individual agent risk preferences. Accordingly, these substantial differences in economic performance are brought about by the differences in deep parameters only when all other things are unchanged, so we should not disregard victim preferences in establishing various recovery policies.¹¹

Given a certain set of parameters, this paper solely investigates the recovery process when severe capital destruction is caused by a natural disaster like the GEJET. Full-scale restoration of production and supply chains is understandably crucial for economic recovery, and our study further demonstrates

¹⁰In consequence, it can probably be assumed that the magnitude of the household elasticity parameter has a relatively larger value during the disaster period.

¹¹Recently, Hanaoka et al. (2015) and Ohtake et al. (2015) empirically investigated whether agent risk preferences changed before and after the GEJET, using panel datasets extracted from the Survey of Life Satisfaction and Preferences promoted by the Global Center of Excellence (GCOE) project “Human Behavior and Socioeconomic Dynamics” at Osaka University. These papers clarify that major disaster can affect the degree of individuals’ risk aversion.

the substantial importance of policy considerations regarding victims involved in recovery programs.

4. Concluding remarks

This paper further investigated the process of recovery from large-scale natural disasters, including the 2011 GEJET, using an extended model of Hosoya (2015). A remarkable feature of the present model is that both the utility and the production functions include public infrastructure as stocks. Our main results are summarized as follows.

Firstly, the benchmark model *without* capital damage by the disaster replicated convergence properties of standard endogenous growth models. Namely, convergence in this model is relatively fast. For the model *with* capital destruction of about 10–20%, we attempted to estimate a transition period between the old and new equilibriums. In our context, the transition period corresponds to the recovery period from the GEJET. The recovery level at present is predicted to be approximately 30% of the overall processes, and we therefore forecast that it will take another 25 years to complete the project from now. This is a long period, but considering the scale of that disaster, full recovery within a single generation can be considered a remarkable achievement.

A highlight of this paper was quantitatively grasping the effect of public concerns about infrastructure on the speed of convergence and the recovery period. This extension is considered to be entirely valid, as it embraces victim preferences in emergency situations. The result of numerical analysis verified the meaning of the approach, implying that appropriate infrastructures implemented by recovery policies in recognition of victim preferences substantially accelerate recovery and shorten the recovery period. This finding is important in that it forms the modality of recovery.

We further examined the relation between several combinations of deep parameters (i.e., the intertemporal elasticity of substitution and public concerns about infrastructure) and recovery performance. Through this investigation, we found that, all other things being equal, the observed differences in economic performance are brought about by the differences in these parameters only. There is a tendency to emphasize production activities, but our results imply that one should not disregard victim-oriented recovery policies.

The results presented in this paper are from a limited point of view, and so they require careful handling. We hope, however, that these results will provide a basis for discussing various recovery issues. Related issues requiring further investigation remain, such as building models that better represent actual conditions in the affected area and performing numerical simulations.

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Appendix A. Derivation of (3)

Using (1) and (2), we formulate the current-value Hamiltonian, \mathcal{H} as

$$\mathcal{H} \equiv \frac{(CH^\sigma)^{1-\theta} - 1}{1-\theta} + \lambda[(1-\tau)K^\alpha H^{1-\alpha} - C],$$

where λ is the co-state variable associated with constraint (2). Since the level of public infrastructure is given for the household, from the first-order necessary conditions $\partial\mathcal{H}/\partial C = 0$ and $\dot{\lambda} = -\partial\mathcal{H}/\partial K + \lambda\rho$, we can obtain

$$\frac{(CH^\sigma)^{1-\theta}}{C} = \lambda, \quad (\text{A1})$$

$$\alpha(1-\tau) \left(\frac{K}{H}\right)^{\alpha-1} - \rho = -\frac{\dot{\lambda}}{\lambda}, \quad (\text{A2})$$

together with the usual transversality condition

$$\lim_{t \rightarrow +\infty} \lambda(t)K(t)e^{-\rho t} = 0. \quad (\text{A3})$$

When (A3) holds, the necessary conditions (A1) and (A2) are also sufficient under the resource constraint.

Log-differentiating (A1) leads to

$$-\theta g_C + \sigma(1-\theta)g_H = g_\lambda. \quad (\text{A4})$$

Applying (A2) to (A4) and rearranging, we obtain (3) as written in the text.

Appendix B. Proof of Proposition 2

From the corresponding Jacobian (see Appendix C), we obtain

$$\text{Det } J^* = -\frac{\alpha}{\theta}(1-\alpha)(1-\tau)X^*(Z^*)^{\alpha-1} - \left(\frac{\theta - \sigma + \sigma\theta}{\theta}\right) \delta\tau(\alpha + \epsilon)X^*(Z^*)^{\alpha+\epsilon}.$$

In view of the assumption ($\theta \geq \sigma/(1+\sigma)$), $\text{Det } J^* < 0$ is proved. The negative sign implies that the equilibrium is locally saddle-path stable.

Appendix C. Derivation of theoretical speed of convergence

To obtain the speed of convergence, we first present the Jacobian related to the model and then derive a characteristic polynomial. The Jacobian of the reduced dynamical system characterized by (5) and (6) is represented as the 2×2 matrix

$$J \equiv \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{bmatrix} \frac{\partial \dot{X}}{\partial X} & \frac{\partial \dot{X}}{\partial Z} \\ \frac{\partial \dot{Z}}{\partial X} & \frac{\partial \dot{Z}}{\partial Z} \end{bmatrix},$$

where

$$\begin{aligned} a_{11} &= \left. \frac{\partial \dot{X}}{\partial X} \right|_{\text{BGP}} = X^*, \\ a_{12} &= \left. \frac{\partial \dot{X}}{\partial Z} \right|_{\text{BGP}} = \left(\frac{1-\theta}{\theta} \right) \delta \sigma \tau (\alpha + \epsilon) X^* (Z^*)^{\alpha+\epsilon-1} \\ &\quad + \left(\frac{\alpha-\theta}{\theta} \right) (\alpha-1)(1-\tau) X^* (Z^*)^{\alpha-2}, \\ a_{21} &= \left. \frac{\partial \dot{Z}}{\partial X} \right|_{\text{BGP}} = -Z^*, \\ a_{22} &= \left. \frac{\partial \dot{Z}}{\partial Z} \right|_{\text{BGP}} = (\alpha-1)(1-\tau)(Z^*)^{\alpha-1} - \delta \tau (\alpha + \epsilon) (Z^*)^{\alpha+\epsilon}, \end{aligned}$$

where an asterisk (*) denotes a value evaluated at the BGP. Incidentally, the BGP values of X and Z correspond to the solutions of the nonlinear simultaneous equations

$$\begin{aligned} X^* + \left(\frac{\alpha-\theta}{\theta} \right) (1-\tau)(Z^*)^{\alpha-1} + \left(\frac{1-\theta}{\theta} \right) \delta \sigma \tau (Z^*)^{\alpha+\epsilon} - \frac{\rho}{\theta} &= 0, \\ X^* - (1-\tau)(Z^*)^{\alpha-1} + \delta \tau (Z^*)^{\alpha+\epsilon} &= 0, \end{aligned}$$

where $X^* > 0$ for a positive g . To satisfy this, we need $X^* = (1-\tau)(Z^*)^{\alpha-1} - g > 0$. For the numerical results in this paper, the positivity condition on X^* is naturally satisfied. Now, as I stands for the identity matrix, the characteristic polynomial can be written as $\text{Det}(J^* - \lambda I) = 0$. Consequently we have

$$\lambda^2 + (V_1 + V_2 - X^*)\lambda - \left(\frac{\alpha}{\theta} V_1 + \left(\frac{\theta - \sigma(1-\theta)}{\theta} \right) V_2 \right) X^* = 0,$$

where $V_1 \equiv (1-\alpha)(1-\tau)(Z^*)^{\alpha-1}$ and $V_2 \equiv \delta \tau (\alpha + \epsilon) (Z^*)^{\alpha+\epsilon}$. This equation has two roots, denoted by λ_1 (negative and stable root) and λ_2 (positive and unstable root). λ_1 is given by (7) in the text.

Appendix D. Numerical algorithm for obtaining λ_1

First, we specify the nonlinear equation $f(Z)$ to obtain the steady-state value of Z , as

$$f(Z) = \frac{\alpha(1-\tau)}{\theta}(\psi Z)^{\alpha-1} - \left(\frac{\theta - \sigma(1-\theta)}{\theta}\right) \delta \tau (\psi Z)^{\alpha+\epsilon} - \frac{\rho}{\theta},$$

where ψ is a scale parameter on Z . As is obvious, ψ equals to unity in the benchmark case. We then change the value depending on the analytical situation (i.e., the difference in the rate of capital destruction). Second, we search for Z^* satisfying $f(Z) = 0$ under given parameters. Third, using the relevant Z^* , we obtain X^* given by

$$X^* = \frac{\rho}{\theta} - \left(\frac{\alpha - \theta}{\theta}\right) (1 - \tau)(Z^*)^{\alpha-1} - \left(\frac{1 - \theta}{\theta}\right) \delta \sigma \tau (Z^*)^{\alpha+\epsilon}.$$

As a consequence, these steps lead to obtaining λ_1 .

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