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Fumiaki Ishizuka

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JICA Ogata Sadako Research Institute for Peace and Development, Japan International Cooperation Agency (JICA)
10-5 Ichigaya Honmura-cho, Shinjuku-ku, Tokyo, 162-8433, JAPAN
TEL: +81-3-3269-3374
FAX: +81-3-3269-2054

Forecasting Infrastructure Investment Requirements under Population Decline: A Stock-Flow-Consistent Bayesian Analysis of Japanese Prefectures

Fumiaki Ishizuka*

Abstract

This paper develops a stock-flow-consistent framework for forecasting subnational infrastructure investment under population decline. Sector-specific Bayesian hierarchical dynamic models are estimated for Japan's 47 prefectures over fiscal years 2000–2020 for roads, water supply, sewerage, and educational facilities. Posterior stock paths are projected to 2050 using official population projections and alternative real-income paths, then converted into annual gross investment with accounting-based productive-capacity-loss rates. The conversion separates new expansion from sustaining capital and records capacity exit when productive capacity surviving from the preceding year exceeds the next-period model-implied stock. Under the preferred specification, national road stock rises by 7.8% between observed 2020 and 2050, whereas water supply, sewerage, and educational facilities decline by 3.4%, 12.7%, and 27.5%. Aggregate gross investment falls from ¥9.12 trillion in 2021 to ¥6.95 trillion in 2050, yet sustaining capital accounts for about 80% of the 2050 total. Road expansion is fairly robust in direction but sensitive in magnitude to the estimation window and income path; water supply is specification-dependent, while contractions in sewerage and educational facilities are more stable. Remaining expansion is geographically concentrated, so national totals conceal a near-complete shift to sustaining capital in many prefectures. The results do not support treating depopulation as a basis for uniform investment cuts. Long-term planning should distinguish expansion, sustaining capital, and capacity exit and reallocate fiscal and technical resources across sectors and regions. Japan provides an early case for other mature and emerging economies facing demographic decline and inherited infrastructure. The estimates are conditional planning benchmarks, not welfare-optimal stocks or engineering requirements.

Keywords: Infrastructure, Public capital, Population decline, Japan, Bayesian hierarchical model
JEL Codes: C11, C53, H54, R53

* Senior Research Fellow, JICA Ogata Research Institute for Peace and Development. (Ishizuka.Fumiaki@jica.go.jp)

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1. Introduction

Public infrastructure is a long-lived input into economic activity and the delivery of essential services. Because investment decisions made today shape service capacity, capital-replacement obligations, and fiscal commitments for decades, credible estimates of future stock paths and investment requirements are central to long-term planning. The problem changes when population growth slows or reverses. Demographic contraction may reduce required capacity in some sectors and places, but it does not remove the need to replace or substantially rehabilitate assets that remain necessary. Income growth, spatial concentration, and network functions may also sustain or increase requirements elsewhere.

These tensions are especially visible in Japan, where population decline, aging infrastructure, and fiscal constraints coexist with pronounced regional heterogeneity. Recent research documents faster depopulation and rising per capita public-service costs in rural areas, together with further concentration of population and economic activity in a smaller set of urban centers (Giannone et al., 2026; Mori and Murakami, 2025). Similar conditions are likely to emerge in other advanced and middle-income economies that accumulated extensive infrastructure during periods of rapid growth and urbanization. Japan therefore provides an early case for studying infrastructure adjustment after the era of broad-based network expansion.

A widely used top-down approach projects infrastructure stocks or service demand from historical relationships with population, income, urbanization, and economic structure, and then converts the projected stocks into investment requirements. Fay and Yepes (2003) established an influential version of this approach, and subsequent studies extended it to broader country groups and incorporated replacement, access gaps, and climate-related costs (Ruiz-Núñez and Wei, 2015; Asian Development Bank, 2017; Branchoux et al., 2018). These studies provide useful aggregate benchmarks, but they typically estimate national or multicountry relationships, impose common parameters across heterogeneous regions, and rarely propagate parameter uncertainty through the stock-to-investment conversion. They also do not always make explicit how replacement or rehabilitation expenditure should be adjusted when required capacity contracts.

A related literature distinguishes investment that expands capacity from capital expenditure that sustains the productive service capacity of inherited assets. New construction raises capacity, whereas replacement and major rehabilitation restore capacity lost through retirement and age-related efficiency decline. Underinvestment in the latter can distort the allocation of public resources toward visible expansion projects (Rioja, 2003; Kalaitzidakis and Kalyvitis, 2004). The distinction is particularly important under population decline: net expansion may weaken, yet substantial capital formation can remain necessary to sustain the capacity that continues to be required.

Research on Japan illustrates both the importance and the complexity of this transition. Ishizuka et al. (2019) show that replacement and rehabilitation expenditure may remain substantial even when demographic contraction lowers projected stocks. Kameda et al. (2026) find that the productivity of public capital varies with demographic structure across Japanese prefectures. These studies also underscore that a stock path inferred from historical socioeconomic relationships is not a welfare-maximizing target. Existing work has not combined subnational parameter heterogeneity, dynamic stock adjustment, posterior forecast uncertainty, and an explicit stock-flow treatment of investment when required capacity declines.

This paper develops such a framework for Japan's 47 prefectures and four infrastructure sectors: roads, water supply, sewerage, and educational facilities. It forecasts prefecture- and sector-specific productive-capital paths through fiscal year 2050 and converts them into annual gross investment requirements using a capital-accumulation identity. The framework separates new expansion investment from sustaining capital investment and explicitly records as capacity exit any productive capacity surviving from the preceding year that is not carried forward into the next-period model-implied stock.

Sector-specific Bayesian hierarchical dynamic models are estimated for fiscal years 2000–2020. Productive capital depends on lagged stock, the relevant population measure, real per capita prefectural income, urbanization, and persistent prefectural heterogeneity. Prefecture-specific intercepts capture durable differences in stock levels, while prefecture-specific income coefficients allow income responsiveness to vary across regions. Partial pooling regularizes unit-level estimates in a panel with relatively short time series, consistent with hierarchical demand forecasting and dynamic-panel forecasting approaches (Bhuwalka et al., 2023; Liu et al., 2020). Posterior draws are recursively projected using official population projections and alternative income paths. A sector-specific, accounting-based productive-capacity-loss rate then converts each stock path into gross investment. Finally, a Shapley decomposition attributes deviations from a fixed-covariate reference path to future demographic and income paths (Shapley, 1953; Shorrocks, 2013; Audoly et al., 2025).

The preferred specification implies heterogeneous adjustment rather than uniform contraction. Between observed 2020 stocks and the 2050 baseline forecast, the model-implied national road-stock rises by 7.8%, whereas water supply declines by 3.4%, sewerage by 12.7%, and educational facilities by 27.5%. The direction of the road result is fairly robust, although its magnitude is sensitive to the estimation window and income path. Contractions in sewerage and educational facilities are robust across the main alternatives, while water supply is more specification-sensitive. Aggregate annual gross investment for the four sectors falls from ¥9.12 trillion in 2021 to ¥6.95 trillion in 2050, but it remains substantial because productive capacity continues to be lost. Sustaining capital accounts for about 80% of the 2050 total. Regional results show that

expansion remains concentrated in a limited number of prefectures, while investment in a typical prefecture becomes almost entirely sustaining capital.

The paper makes three contributions. First, it extends top-down infrastructure forecasting to a mature, depopulating economy using subnational sectoral data and Bayesian partial pooling, thereby incorporating regional heterogeneity and posterior parameter uncertainty conditional on the specified covariate paths. Second, it connects model-implied productive-capital paths to annual gross investment through an explicit stock-flow identity that records productive capacity not carried forward into the next-period stock path as capacity exit. Third, it quantifies how demographic and income paths alter model-implied stock paths and the composition and regional allocation of investment. Overall, the paper provides a versatile framework for estimating infrastructure requirements while ensuring consistency between stock and flow, which can be applied to other mature and emerging economies that will soon face similar challenges.

The estimates are conditional planning benchmarks, not engineering requirements, welfare-maximizing stocks, project-level investment plans, or funding-gap estimates. Observed stocks themselves reflect past budgetary, institutional, and political constraints, and the estimated coefficients are reduced-form predictive relationships rather than causal effects. Actual infrastructure needs also depend on service standards, technology, efficiency, and policy choices and should not be reduced to a single invariant funding-gap number (Rozenberg and Fay, 2019). The framework is intended to support national and regional scenario planning; it does not replace engineering or facility-level asset-management assessments.

The remainder of the paper is organized as follows. Section 2 presents the conceptual framework and empirical strategy. Section 3 describes the data and forecast assumptions. Section 4 reports estimation and model assessment. Sections 5 and 6 present stock and investment projections. Section 7 summarizes robustness and sensitivity analyses. Section 8 discusses the implications, Section 9 sets out the limitations, and Section 10 concludes. Detailed estimates and diagnostics are reported in the Supplementary Material following the references.

2. Conceptual framework and empirical strategy

2.1 Model-implied stock paths and investment requirements

The analysis treats infrastructure investment as capital formation that creates or sustains required productive service capacity. It proceeds in two stages. The first stage forecasts productive-capital stocks implied by future socioeconomic conditions and the historical adjustment of observed stocks. The second stage inserts those paths into a capital-accumulation identity to derive annual gross investment requirements.

The first-stage forecasts are conditional model-implied stock paths obtained by recursively

applying reduced-form relationships estimated from observed prefectural stock dynamics to specified future socioeconomic paths. These paths are interpreted as conditional planning benchmarks rather than engineering minima, welfare-maximizing stocks, or unconstrained latent demand for infrastructure. Because historical stocks also embody past fiscal, institutional, and political constraints, the framework does not purge all supply-side influences from the data. The coefficients are therefore interpreted as predictive parameters rather than structural demand elasticities or causal effects.

The second stage compares productive capacity surviving from the previous year with the current model-implied stock. When the model-implied stock increases, the framework distinguishes investment that expands the stock from capital expenditure that restores productive capacity lost through retirement and age-related efficiency decline. When surviving capacity exceeds the next-period model-implied stock, the difference is recorded as capacity exit, as defined formally in Section 2.4. Throughout the paper, "investment requirement" refers to the gross capital formation implied by the stock-flow identity for attaining the model-implied stock path.

An alternative would be to forecast expenditure directly from socioeconomic conditions. Realized investment, however, reflects annual budget constraints, grant systems, project timing, disaster restoration, and political priorities in addition to long-run service-capacity considerations. The two-stage approach separates these short-run expenditure fluctuations conceptually from the capital formation implied by a projected service-capacity path.

2.2 Estimation of model-implied infrastructure stock paths

Let K_{it}^{*} denote the model-implied productive-capital stock in prefecture i and fiscal year t. The model-implied stock is related to population, income, and urbanization as follows:

$$\ln K_{it}^{*} = a_i + \theta' X_{it} + u_{it} \tag{1}$$

where i indexes prefectures, t indexes fiscal years, X_{it} is the vector of socioeconomic covariates, and a_i is a prefecture-specific baseline stock component. Sector subscripts are omitted because each sector is estimated separately.

Observed infrastructure stock K_{it} does not adjust instantaneously to the level implied by current socioeconomic conditions. Planning, budgeting, construction, institutional adjustment, and the long life of existing assets all generate gradual adjustment:

$$\ln K_{it} - \ln K_{i,t-1} = \lambda\left(\ln K_{it}^{*} - \ln K_{i,t-1}\right) + \nu_{it} \qquad 0 < \lambda \leq 1 \tag{2}$$

where λ is the share of the gap between the current stock and the model-implied stock that is

closed within one year.

Substituting equation (1) into equation (2) yields the estimable dynamic specification with a lagged dependent variable:

$$\begin{gathered} \ln K_{it} = \rho \ln K_{i,t-1} + \beta' X_{it} + \alpha_i + \varepsilon_{it} \\ \rho = 1 - \lambda, \quad \beta = \lambda\theta, \quad \alpha_i = \lambda a_i \end{gathered} \tag{3}$$

where ρ is the reduced-form persistence parameter governing how strongly past productive capital carries into the current stock. It combines delayed adjustment to socioeconomic conditions, planning and budget inertia, asset longevity, and historical investment paths. The remaining coefficients describe conditional predictive relationships given lagged stock and prefecture-specific factors; they are not interpreted as structural causal effects or long-run demand elasticities.

2.3 Estimation methods and model assessment

Three sector-specific models are compared. Model 1 is a non-Bayesian prefecture fixed-effects benchmark. Model 2 is a Bayesian hierarchical model with prefecture-specific random intercepts. Model 3 additionally permits the coefficient on real per capita prefectural income to vary across prefectures. The Bayesian models represent regional parameter distributions and propagate posterior uncertainty into recursive forecasts.

Model 1 controls for time-invariant prefecture characteristics through fixed effects:

$$\ln K_{it} = \rho \ln K_{i,t-1} + \beta' X_{it} + \alpha_i + \varepsilon_{it} \tag{4}$$

where α_i denotes the prefecture fixed effect. Standard errors are clustered by prefecture. Because the model contains a lagged dependent variable in a relatively short panel, the fixed-effects estimates may be subject to Nickell bias. Model 1 is therefore used as a predictive and sign-comparison benchmark rather than as a source of causal parameters.

Model 2 represents persistent prefectural differences in baseline infrastructure levels through a hierarchical random intercept:

$$\begin{gathered} \ln K_{it} \sim \text{Normal}(\mu_{it}, \sigma^2) \\ \mu_{it} = \beta_0 + b_{0i} + \rho \ln K_{i,t-1} + \beta' X_{it} \\ b_{0i} \sim \text{Normal}(0, \tau_0^2) \end{gathered} \tag{5}$$

where μ_{it} is the conditional mean, β_0 is the population-level intercept, b_{0i} is prefecture i's deviation, and τ_0 is the between-prefecture standard deviation. Continuous predictors are

standardized within each estimation sample, while the dependent variable remains in log levels. The population-level intercept has a normal prior centered on the sample mean of the dependent variable with standard deviation 2; slope coefficients have Normal(0, 0.7^2) priors; and residual and group-level standard deviations have Exponential(2) priors. Because predictors are standardized, the normal priors allow broad coefficient ranges, while the exponential priors mildly regularize positive scale parameters toward smaller values. The prior set is therefore weakly informative rather than noninformative.

Model 3 adds a prefecture-specific coefficient on real per capita income:

$$\begin{gathered} \ln K_{it} \sim \text{Normal}(\mu_{it}, \sigma^2) \\ \mu_{it} = \beta_0 + b_{0i} + ln\, K_{i,t-1} + (\beta_1 + b_{1i}) y_{it} + \beta_z{}' Z_{it} \\ \begin{pmatrix} b_{0i} \\ b_{1i} \end{pmatrix} \sim \mathcal{N}_2 \left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \Sigma \right) \end{gathered} \tag{6}$$

where y_{it} is real per capita prefectural income, Z_{it} contains the other covariates, β_1 is the population-level income coefficient, and b_{1i} is prefecture i's deviation. The covariance matrix Σ permits correlation between the prefecture-specific intercept and income coefficient and receives an LKJ(4) prior, which favors correlations near zero over near-perfect positive or negative correlations without fixing the correlation at zero. Income is the principal scenario variable whose response plausibly differs across regions. Allowing every coefficient to vary would be excessive relative to the available time dimension and would widen long-run uncertainty without a clear forecasting gain.

Bayesian estimation is assessed using R-hat, bulk and tail effective sample sizes, divergent transitions, and maximum-treedepth hits. Prior predictive checks evaluate whether the regularizing priors imply plausible outcome scales before conditioning on the data. Posterior predictive checks assess whether the fitted models reproduce the broad distribution and time profile of observed stocks.

Temporally ordered holdout exercises compare all three models on common data. One-step-ahead forecasts use the observed lagged stock in each evaluation year. Recursive forecasts use the last observed stock only at the start of the holdout and feed each prediction into the following year. Both a five-year holdout (2016–2020, estimated through 2015) and a ten-year holdout (2011–2020, estimated through 2010) are evaluated using root mean squared error (RMSE) in log points. The longer exercise provides a more demanding test of error propagation, although neither holdout directly validates the full 2021–2050 horizon.

2.4 From model-implied stock paths to annual gross investment requirements

The principal policy quantity is annual gross capital formation consistent with the projected stock path. The model-implied productive-capital paths are therefore translated into investment flows using an explicit capital-accumulation identity.

Productive capital measures the service capacity remaining after accounting for asset retirement and age-related efficiency decline. Although the stock observed in fiscal year $t-1$ already embodies earlier losses, additional productive capacity is lost between $t-1$ and t. The annual effective productive-capacity-loss rate δ_t is calibrated from the following accounting relations:

$$\delta_t = \frac{K_{t-1} + F_t - K_t}{K_{t-1}}$$
$$\delta = \text{median}_{t \in \mathcal{T}}(\delta_t) \tag{7}$$

where K_t is national productive capital in fiscal year t and F_t is national real gross investment. The residual $K_{t-1} + F_t - K_t$ is interpreted as productive capacity lost during year t. Dividing the residual by K_{t-1} gives the annual effective loss rate δ_t. It combines physical retirement with age-related declines in productive efficiency. The baseline sector-specific rate δ is the median annual rate over the calibration period $\mathcal{T}$.

The loss rate is calibrated from national sectoral stock and investment series and applied uniformly across prefectures within a sector. Regional heterogeneity is modeled in the stock equation rather than inferred from noisy prefecture-level accounting residuals. The parameter is not a structurally estimated physical depreciation rate; it is an externally calibrated accounting device for converting projected productive-capital stocks into gross investment.

Using the calibrated rate, gross investment required to attain the model-implied stock in fiscal year t is defined as:

$$I_{it} = \max\{K_{it}^* - (1-\delta)K_{i,t-1}^*, 0\} \tag{8}$$

where K_{it}^* is the model-implied stock and $(1-\delta)K_{i,t-1}^*$ is productive capacity surviving from the preceding year $t-1$ in the absence of new capital formation. Gross investment equals the positive gap between the current model-implied stock and surviving capacity. When surviving capacity exceeds the next-period model-implied stock, the difference is recorded as capacity exit. This is an accounting label for productive capacity that is not carried forward into the model-implied stock path; it does not imply that the capacity is physically redundant, immediately scrapped, or optimally decommissioned. In practice, the reduction may occur through non-replacement after retirement, closure, consolidation, conversion, or disposal. The model does not

separately identify these mechanisms or their transition costs.

Gross investment I_{it} is further decomposed into new expansion investment and sustaining capital investment:

$$I_{it}^{N} = \max\{K_{it}^{*} - K_{i,t-1}^{*}, 0\}$$
$$I_{it}^{S} = I_{it} - I_{it}^{N} \tag{9}$$

where new expansion investment I_{it}^{N} is the positive annual increase in the model-implied stock itself. Sustaining capital investment I_{it}^{S} restores productive capacity lost through retirement and age-related efficiency decline, but only to the extent needed to attain the current model-implied stock. It includes replacement and major capital rehabilitation that materially restores service capacity or useful life. It excludes routine operations, inspection, cleaning, minor repairs, and other current expenditures. Aggregate stock data does not permit replacement and major rehabilitation to be identified separately, so they are combined.

2.5 Conditional dynamics and model-based attribution

Two exercises clarify why projected paths differ across sectors. First, the recursive dynamics are evaluated with socioeconomic covariates held at their 2020 values, and the associated conditional fixed points are calculated. Second, changes in stock and investment are attributed to future demographic and income paths using the Shapley value (Shapley, 1953; Shorrocks, 2013; Audoly et al., 2025). Returning the standardized model to the original log-stock scale gives the recursive posterior conditional mean:

$$\ln K_{it}^{*,\omega} = \eta_{it}^{\omega} + \phi \ln K_{i,t-1}^{*,\omega} \tag{10}$$

where ω indexes a forecast scenario, $K_{it}^{*,\omega}$ is the recursive model-implied stock path, η_{it}^{ω} collects the non-lagged component, and ϕ is persistence on the original log-stock scale. Sector and posterior-draw subscripts are suppressed for readability. Recursion begins from observed productive capital in 2020.

Let the reference scenario hold population, real per capita income, and urbanization at their 2020 values ($\omega = 000$). The non-lagged component is then constant over time within each prefecture ($\eta_{it}^{000} = \eta_{i}^{000}$). Provided that $|\phi| < 1$, the dynamic process converges to the following conditional fixed point:

$$\ln K_{i,\infty}^{*,000} = \frac{\eta_{i}^{000}}{1-\phi}$$
$$|\phi| < 1 \tag{11}$$

where the fixed point $K_{i,\infty}^{*,000}$ is the mathematical convergence value obtained by repeatedly applying the estimated reduced-form dynamics under fixed 2020 covariates. It is not a socially optimal stock or evidence that the observed stock is excessive or deficient. If observed 2020 stock lies below the fixed point, the reference path adjusts upward; if it lies above the fixed point, the path adjusts downward.

The Shapley value assigns each future path its average marginal contribution over all possible orders in which the paths can be introduced. Demography, real per capita income, and urbanization are each treated as a grouped input covering all prefectures and forecast years. Because urbanization is held at its 2020 value in the forecasts, its contribution is zero by construction.

The 2020–2050 stock change can be written as a reference-path dynamic adjustment plus the Shapley contributions of the future covariate paths:

$$100\left(\frac{K_{2050}^{*,111}}{K_{2020}}-1\right)=100\left(\frac{K_{2050}^{*,000}}{K_{2020}}-1\right)+\Phi_D+\Phi_Y+\Phi_U \tag{12}$$

where the left-hand side is the change from observed national productive capital in 2020 to the 2050 baseline model-implied stock. The first term on the right is the change under fixed 2020 covariates. The remaining terms are the demographic, income, and urbanization Shapley contributions, expressed as percentage-point contributions relative to observed 2020 stock. For every posterior draw, the Shapley contributions sum exactly to the difference between the baseline and fixed-covariate forecasts. The decomposition is an internally consistent attribution within the forecasting model, not a causal decomposition.

3. Data and forecast assumptions

3.1 Infrastructure stock data and estimation sample

The dependent variables are prefecture-by-sector productive-capital stocks from the Cabinet Office's Public Capital Stock Estimates (Cabinet Office of Japan, 2024), expressed in million yen at 2015 prices and recorded by fiscal year. Fiscal-year data are used because prefectural income, a central explanatory variable, is available on that basis. Population and urbanization observations dated October 1 are matched to the corresponding fiscal year.

Productive capital is the preferred stock concept because it measures the service-producing capacity remaining after age-related efficiency decline, which aligns with the paper's model-implied capacity benchmark. Net capital stock, which measures asset value after depreciation and obsolescence, is used in fixed-effects robustness specifications.

The preferred estimation period is fiscal years 2000–2020, the interval for which prefecture-level

age-specific population and socioeconomic covariates can be assembled consistently. Earlier decades combined rapid growth, domestic-demand expansion, and broad network formation and may represent a different stock-formation regime. The panel contains 47 prefectures over 21 years, or 987 observations per sector. Alternative windows beginning in 1990 and 2005, and a specification ending in 2019, are examined in the robustness analysis.

3.2 Infrastructure sectors

The analysis covers roads, water supply, sewerage, and educational facilities. The last category includes school and academic facilities and excludes social education facilities such as public libraries and museums. Together these sectors represent regional access and logistics, basic household services and sanitation, urban environmental infrastructure, and facilities supporting human-capital formation, while also providing consistent prefectural stock and forecast-covariate series. Ports, airports, and railways are excluded because their service areas frequently cross prefectural boundaries. Roads also include interregional links, but their correspondence with prefectural access, commuting, logistics, and local service areas is comparatively stronger.

3.3 Socioeconomic covariates

The covariates are one-year lagged stock, population, real per capita prefectural income, and urbanization. All variables except urbanization are entered in logs, and all continuous predictors are standardized for Bayesian estimation. Table 1 reports descriptive statistics.

Table 1: Descriptive statistics

Panel A. Variables used in the preferred specifications							
Variable	**Unit**	**N**	**Mean**	**Std. dev.**	**Minimum**	**Median**	**Maximum**
Productive capital stock: roads	million yen	987	5,419,592	3,844,351	1,624,142	3,936,135	22,705,800
Productive capital stock: water supply	million yen	987	1,096,501	1,112,315	175,660	669,617	7,211,102
Productive capital stock: sewerage	million yen	987	1,729,982	1,891,457	134,013	986,554	10,412,605
Productive capital stock: educational facilities	million yen	987	1,056,138	880,312	299,050	709,481	5,123,206
Total population	thousand persons	987	2,709	2,637	553	1,706	14,048
Population aged 5-19	thousand persons	987	379	348	72	249	1,668
Per capita prefectural income	thousand yen	987	2,764	526	1,895	2,723	5,884
Urbanization rate	percent	987	51.83	18.67	24.16	45.81	98.55
Panel B. Supplementary variables and alternative definitions							
Variable	**Unit**	**N**	**Mean**	**Std. dev.**	**Minimum**	**Median**	**Maximum**
Net capital stock: roads	million yen	987	4,696,626	3,299,889	1,458,981	3,414,178	19,143,605
Net capital stock: water supply	million yen	987	953,685	961,602	159,903	594,994	6,153,002
Net capital stock: sewerage	million yen	987	1,471,687	1,576,312	122,029	854,161	8,416,801
Net capital stock: educational facilities	million yen	987	764,135	629,647	226,421	520,311	3,679,913
Population aged 5-14	thousand persons	987	244	223	47	163	1,047
Population aged 5-24	thousand persons	987	526	510	95	328	2,586

Notes: The estimation sample covers 47 prefectures over fiscal years 2000–2020. Productive capital stock is used in the preferred specifications; net capital stock and alternative education-age variables are reported as supplementary definitions. Infrastructure stocks and per capita prefectural income are expressed at 2015 prices.

Population data are drawn from the Population Census and Population Estimates (Statistics

Bureau of Japan, various years-a; Statistics Bureau of Japan, various years-b). Total population is used for roads, water supply, and sewerage. The preferred educational-facilities specification uses population aged 5–19, reflecting the concentration of the stock category in primary and secondary education. Populations aged 5–14 and 5–24 are examined as alternatives.

Real per capita prefectural income is constructed from the Prefectural Accounts (Cabinet Office of Japan, various years-a). Growth rates are linked across successive System of National Accounts vintages, and nominal series are converted to 2015 prices using the GDP deflator from the National Accounts (Cabinet Office of Japan, various years-b). Including income per person separately from population distinguishes the association with economic resources and activity from the scale of the resident population.

Urbanization is the population living in densely inhabited districts divided by total population, based on the Population Census (Statistics Bureau of Japan, various years-a). Census observations are available every five years, so intervening fiscal years are linearly interpolated. Land-area and density measures are not included simultaneously because they are closely related to urbanization.

3.4 Future covariate paths

Population for 2021–2050 follows the Regional Population Projections: 2020–2050 (2023 Revision), based on the 2020 Population Census (National Institute of Population and Social Security Research, 2023). The five-year points are linearly interpolated to annual values. The educational-facilities forecast uses projected population aged 5–19.

The baseline income path compounds each prefecture's average annual real per capita income growth rate over 2010–2019. Fiscal year 2020 is excluded from the growth calculation because it may contain an unusually large temporary COVID-19 shock. Optimistic and pessimistic scenarios add or subtract 0.25 percentage points from the prefecture-specific annual baseline growth rate. A separate stress test caps each prefecture's future income at its maximum observed level over 2000–2020.

Urbanization is held at its 2020 value because recent changes are small and no consistent prefecture-level projection to 2050 is available. Its future-path contribution is therefore zero by construction in the Shapley decomposition.

3.5 Effective productive-capacity-loss rates

Calibration uses the national sectoral series in the Cabinet Office's Public Capital Stock Estimates (Cabinet Office of Japan, 2024). Productive capital is measured at 2015 prices, and observed real investment is the sum of real new and improvement expenditure and real disaster-restoration expenditure. The investment series includes new construction, reconstruction, replacement, and

capital repairs that materially extend useful life or productive capacity; it excludes land acquisition and routine current maintenance. The productive-capital series already incorporates asset retirement and age-related efficiency decline. The Cabinet Office constructs the series using sector-specific service lives, Weibull-type retirement profiles, and age-efficiency profiles applied to past real investment; productive efficiency is assumed to decline with asset age. The effective loss rate used here is therefore a reduced-form annual summary of the same stock-accounting system rather than a separately estimated engineering depreciation function.

The baseline rate for each sector is the median annual effective loss rate over 2000–2020, matching the preferred model-estimation period. Alternative calibrations use the 2010–2019 median, the 2016–2020 and 2015–2019 means, a specification excluding disaster-restoration expenditure, and a nonparametric bootstrap distribution of the baseline median based on resampling annual loss rates.

The stock-to-flow conversion uses a common national rate within each sector, while the stock model captures regional heterogeneity. Because the loss rate is an accounting residual between adjacent stock observations and annual investment, it is more sensitive than the stock level to measurement and allocation errors. Calculating prefecture-specific rates could misinterpret those errors as regional differences in asset age, retirement, or efficiency decline.

Table 2 reports the calibrated rates. The baseline median annual rates are 1.516% for roads, 1.424% for water supply, 1.529% for sewerage, and 2.671% for educational facilities. Educational facilities have the highest calibrated loss rate and water supply the lowest. Alternative periods preserve the broad sectoral ordering but generally produce somewhat higher rates. The 2016–2020 means range from 1.507% for water supply to 3.074% for educational facilities. Because both the period and summary statistic differ across these alternatives, the differences are treated as sensitivity checks rather than evidence of a structural time trend.

Table 2: Calibrated effective productive-capacity loss rates by sector

Sector	Baseline: median 2000-2020	Median 2010-2019	Mean 2016-2020	Mean 2015-2019	Excluding disaster restoration
Roads	1.516%	1.536%	1.615%	1.592%	1.450%
Water supply	1.424%	1.485%	1.507%	1.498%	1.385%
Sewerage	1.529%	1.680%	1.752%	1.725%	1.471%
Educational facilities	2.671%	2.912%	3.074%	3.009%	2.611%

Notes: Entries are percentages. The baseline is the median annual accounting-based effective productive-capacity loss rate over 2000–2020. Alternative calibration periods and a specification excluding disaster-restoration investment are shown for sensitivity. These rates are not structurally estimated physical depreciation rates.

The 2000–2020 median is used for the baseline forecasts because it matches the estimation period

and is less sensitive to individual-year fluctuations. Alternative rates are propagated through the investment calculations in Section 7. In addition, all the dataset and R codes required to reproduce the reported tables and figures are archived on Zenodo (Ishizuka, 2026).

4. Estimation and model assessment

4.1 Fixed-effects benchmark estimates

Table S1 reports the fixed-effects benchmarks. Productive capital is the preferred dependent variable, while net capital provides a stock-concept robustness check. Specifications with prefecture and fiscal-year fixed effects, alternative education-age variables, and alternative estimation windows are also reported. The benchmarks are used to assess signs, persistence, and predictive performance rather than to identify causal effects.

Lagged stock is positive and statistically significant in every sector and stock definition. The coefficients range from 0.834 to 0.969 for productive capital and from 0.824 to 0.979 for net capital, indicating strong persistence in observed infrastructure stocks.

Population coefficients vary by sector. For productive capital, total population is positive and significant for sewerage, and population aged 5–19 is positive and significant for educational facilities. Road and water-supply population coefficients are not statistically distinguishable from zero in the preferred prefecture fixed-effects specifications. Educational results remain positive when the age range is changed to 5–14 or 5–24, although significance is less consistent for net capital.

Real per capita income is positive for roads and water supply and negative for sewerage in the productive-capital benchmarks, but these coefficients are not statistically significant. For educational facilities, income is negative and significant for both productive and net capital. These are conditional within-prefecture associations and should not be interpreted as causal income effects.

Urbanization coefficients are small and not stable across sectors and stock concepts. This instability, together with the lack of a credible long-run prefectural urbanization projection, supports holding urbanization fixed in the forecast rather than assigning it a speculative future path.

The benchmarks support the inclusion of the selected covariates but also reveal substantial sectoral heterogeneity. They cannot represent regional coefficient distributions or propagate parameter uncertainty, and the lagged dependent variable may introduce finite-T bias. The hierarchical Bayesian models are therefore used for the principal forecasts.

4.2 Bayesian posterior estimates

Table 3 reports posterior medians for the preferred Model 3; the complete Model 2 and Model 3 estimates are in Table S2. Continuous predictors are standardized, so the reported slopes measure the change in log productive capital associated with a one-standard-deviation change in a predictor, conditional on the other variables. The standardized lag coefficient is not itself persistence on the original log-stock scale; detailed persistence and half-life results are reported in Table S3.

Table 3: Preferred Model 3 posterior estimates

Parameter	Roads	Water supply	Sewerage	Educational facilities
Lagged stock	0.494 [0.489, 0.498]	0.695 [0.688, 0.701]	0.708 [0.703, 0.713]	0.625 [0.620, 0.630]
Per capita prefectural income	0.002 [-0.002, 0.005]	0.003 [-0.000, 0.006]	0.000 [-0.004, 0.004]	-0.008 [-0.010, -0.005]
Population	0.012 [-0.004, 0.025]	0.056 [0.049, 0.062]	0.113 [0.097, 0.127]	0.020 [0.016, 0.024]
Urbanization rate	0.024 [0.015, 0.032]	0.007 [0.000, 0.015]	-0.026 [-0.036, -0.017]	-0.006 [-0.010, -0.003]
Corr(intercept, income slope)	0.116 [-0.212, 0.439]	-0.276 [-0.536, 0.029]	-0.344 [-0.577, -0.060]	-0.206 [-0.570, 0.214]
SD prefecture intercept	0.036 [0.026, 0.052]	0.018 [0.014, 0.023]	0.067 [0.052, 0.090]	0.006 [0.005, 0.009]
SD income slope	0.011 [0.009, 0.014]	0.009 [0.007, 0.012]	0.012 [0.010, 0.016]	0.005 [0.003, 0.007]
Residual SD	0.006 [0.006, 0.006]	0.007 [0.007, 0.007]	0.007 [0.007, 0.007]	0.009 [0.008, 0.009]
Original-scale persistence	0.893 [0.885, 0.901]	0.904 [0.896, 0.912]	0.833 [0.827, 0.840]	0.977 [0.969, 0.985]
Half-life (years)	6.1 [5.7, 6.6]	6.8 [6.3, 7.5]	3.8 [3.7, 4.0]	29.3 [22.0, 44.6]

Notes: Entries report posterior medians with 95% credible intervals in brackets. Continuous predictors, including lagged stock, are standardized before estimation, while the dependent variable remains in log levels. Original-scale persistence equals the standardized lag coefficient divided by the estimation-sample standard deviation of lagged log stock. Population denotes total population for roads, water supply, and sewerage and population aged 5–19 for educational facilities.

The posterior estimates reinforce three broad features: strong stock persistence, positive population associations for water supply, sewerage, and educational facilities, and sector-specific relationships with income and urbanization. Several population-level income coefficients include zero, making prefecture-level heterogeneity and long-horizon sensitivity especially important.

Original-scale persistence is below one in every posterior draw; sector-specific posterior summaries and half-lives are reported in Table S3. Educational facilities adjust particularly slowly, helping explain why inherited capacity remains important as the relevant population declines.

Population is positively associated with productive capital for water supply, sewerage, and educational facilities, with 95% credible intervals excluding zero. For roads, the population-level coefficient in Model 3 includes zero. This does not establish that population is irrelevant to roads; rather, after conditioning on lagged stock, urbanization, and heterogeneous income responses, the average short-run association is imprecisely estimated.

The population-level per capita income coefficient in Model 3 includes zero for roads, water supply, and sewerage but is negative for educational facilities. The posterior medians of the group-level standard deviation of prefecture-specific income slopes are 0.011, 0.009, 0.012, and 0.005,

respectively. Because these standard deviations are constrained to be nonnegative, their intervals are not conventional significance tests; the forecasting value of heterogeneous income slopes is assessed through holdout performance and long-run sensitivity.

Urbanization is positively associated with roads and water supply and negatively associated with sewerage and educational facilities in the preferred model. These conditional signs may be consistent with differences in network configuration, maturity, and spatial efficiency, but the model does not identify the underlying mechanisms.

The posterior correlation between the prefecture-specific intercept and income slope is -0.344, with a 95% credible interval of [-0.577, -0.060] for sewerage. Conditional on the other variables, prefectures with higher baseline sewerage stocks tend to have weaker income responsiveness. This is a correlation between random effects, not a causal relationship.

4.3 Bayesian model diagnostics

Markov Chain Monte Carlo (MCMC) diagnostics are reported in Table S4 and original-scale persistence diagnostics in Table S3. The preferred Model 3 converges satisfactorily in all sectors. Prior and posterior predictive checks show no major conflict with the observed scale, sectoral distributions, or annual mean paths (Figure S1, Figure S2, and Figure S3). The predictive checks support the use of Model 3 for conditional forecasting but do not evaluate performance on unused future periods; that evidence comes from the holdout exercises below.

4.4 Model comparison and preferred specification

Table 4 compares the three models over five- and ten-year holdouts. Full evaluation metrics, predictive-interval coverage, and prefecture-cluster bootstrap comparisons of RMSE differences are reported in Table S5, and the RMSE patterns are shown in Figure S4. In the five-year exercise, Model 3 has the lowest one-step RMSE for roads, sewerage, and educational facilities and the lowest recursive RMSE for roads and sewerage; it is nearly tied with Model 1 for water supply, while Model 1 performs slightly better for recursive educational-facility forecasts. In the ten-year exercise, Model 3 performs best for water supply and sewerage, whereas Model 1 performs best for roads and educational facilities. Model 3 is generally superior to, or virtually tied with, the simpler Bayesian random-intercept model.

Table 4: Temporally ordered holdout performance

Sector	Holdout	Evaluation	M1	M2	M3
Roads	10-year	One-step	0.0157	0.0173	0.0173
Roads	10-year	Recursive	0.0569	0.0640	0.0639
Roads	5-year	One-step	0.0112	0.0120	0.0098
Roads	5-year	Recursive	0.0294	0.0320	0.0244
Water supply	10-year	One-step	0.0131	0.0129	0.0124
Water supply	10-year	Recursive	0.0454	0.0458	0.0429

Sector	Holdout	Evaluation	M1	M2	M3
Water supply	5-year	One-step	0.0095	0.0103	0.0096
Water supply	5-year	Recursive	0.0232	0.0260	0.0233
Sewerage	10-year	One-step	0.0137	0.0125	0.0117
Sewerage	10-year	Recursive	0.0464	0.0427	0.0398
Sewerage	5-year	One-step	0.0107	0.0108	0.0077
Sewerage	5-year	Recursive	0.0266	0.0270	0.0170
Educational facilities	10-year	One-step	0.0103	0.0120	0.0117
Educational facilities	10-year	Recursive	0.0398	0.0515	0.0500
Educational facilities	5-year	One-step	0.0129	0.0127	0.0123
Educational facilities	5-year	Recursive	0.0373	0.0399	0.0387

Notes: Entries are root-mean-square errors in log points; lower values indicate better performance. One-step forecasts use observed lagged stock in each evaluation year, while recursive forecasts feed each predicted stock into the following year. M1 is the prefecture fixed-effects benchmark, M2 is the random-intercept model, and M3 additionally allows prefecture-specific income coefficients.

Model 3 is therefore not selected because it minimizes RMSE in every sector and horizon. It is adopted as a common forecasting specification because it performs well overall, represents prefecture-level income heterogeneity, and supplies the joint posterior structure required for regional probabilistic forecasts and nonlinear stock-to-investment transformations. Final projections are compared with Models 1 and 2, alternative estimation windows, and alternative priors. Caution is warranted for the magnitude of the road projection, the direction of water-supply adjustment, and the long-run extrapolation of the educational income coefficient.

5. Projected model-implied infrastructure stocks

5.1 National stock paths through 2050

Figure 1 presents national productive-capital stocks through 2020 and posterior median model-implied requirements for 2021–2050 under Model 3. The four sectors follow markedly different paths, showing that demographic contraction does not translate into a uniform proportional decline in infrastructure capacity.

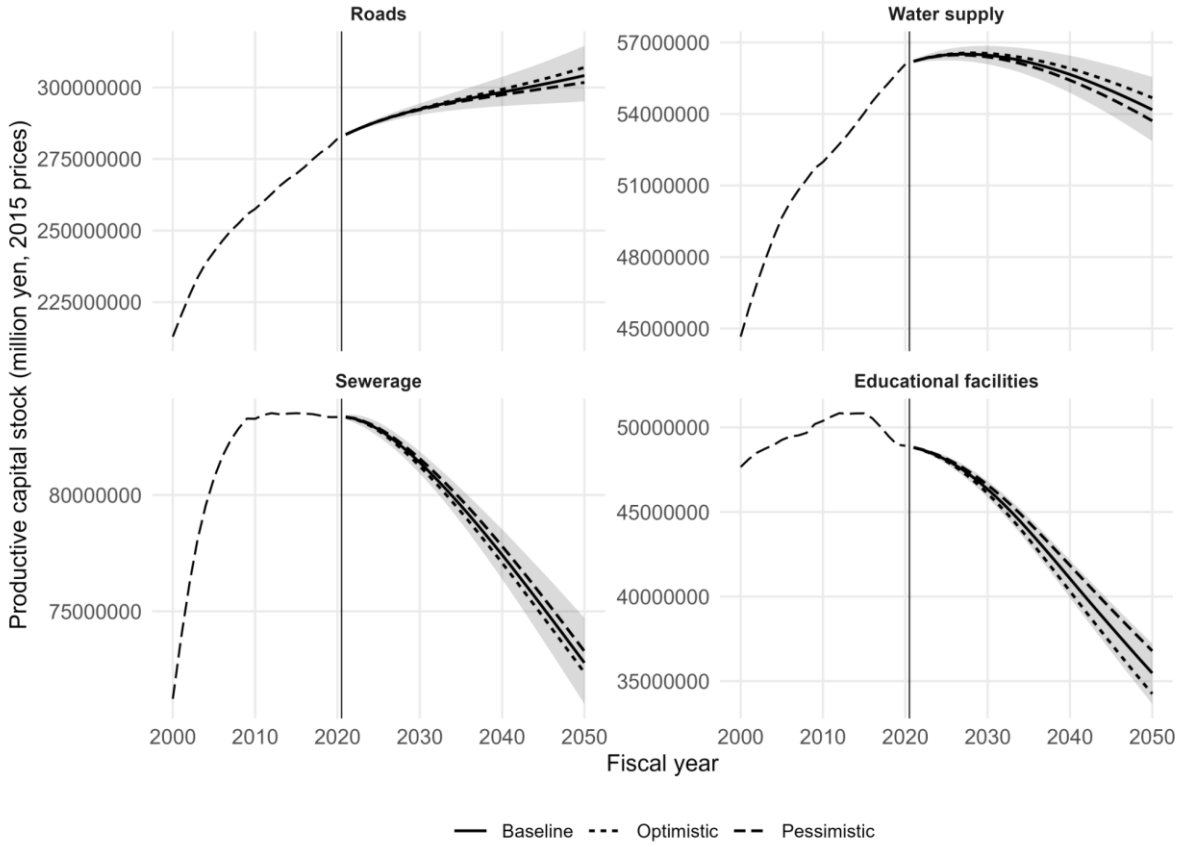


Figure 1: Projected model-implied infrastructure stocks to 2050

Notes: The long-dashed lines show observed national productive capital stock through fiscal year 2020. Scenario lines show posterior median model-implied stock paths for 2021–2050, and shaded bands show 95% posterior credible intervals under the baseline income scenario. The vertical line separates observed and forecast periods. Population follows official prefectural projections, urbanization is held at its 2020 value, and optimistic and pessimistic income growth rates are 0.25 percentage points above or below the baseline. Credible intervals are conditional on the specified socioeconomic paths and do not incorporate uncertainty in future covariates. Monetary values are million yen at 2015 prices.

Under the baseline, the model-implied national road-stock rises gradually to ¥304.0 trillion in 2050. Relative to observed 2020 stock, the increase is 7.8% [4.6%, 11.5%]; the posterior interval for the national aggregate remains above the 2020 level by 2050. Water supply is approximately stable during the early forecast years and then declines to ¥54.2 trillion in 2050. The 2020–2050 change is -3.4% [-5.8%, -1.0%] under the preferred specification. As Section 7 shows, however, water supply is the sector for which the long-run direction is most sensitive to the model and estimation window. Sewerage declines consistently to ¥72.8 trillion in 2050, corresponding to a change of -12.7% [-14.8%, -10.4%] from observed 2020 stock. The decline is larger and more robust than for water supply. Educational facilities show the largest contraction, reaching ¥35.5 trillion in 2050. The change from observed 2020 stock is -27.5% [-31.2%, -23.9%]. As the decomposition in Section 5.2 shows, this decline is associated roughly equally with the projected fall in population aged 5–19 and the future income path under the estimated negative conditional

income relationship, with a smaller negative reference-path adjustment. The model does not separately identify the historical contribution of school consolidation, which may be embedded in the observed stock dynamics.

Changing annual income growth by plus or minus 0.25 percentage points does not reverse the baseline direction of any sector. Higher income raises projected roads and water-supply stocks. For sewerage and educational facilities, the estimated population-level income coefficients are approximately zero and negative, respectively, so the optimistic income path produces a lower national median than the pessimistic path. These are mechanical consequences of the estimated conditional relationships, not welfare judgments about the desirable response to income growth.

5.2 Model-implied contributions to stock changes

Figure 2 decomposes the national change from observed 2020 stock to the 2050 baseline forecast into the reference-path dynamic adjustment and the Shapley contributions of future demographic and income paths. Complete posterior decomposition results are reported in Table S6; the conditional fixed points underlying the reference path are reported in Table S7 and Figure S5. Urbanization is omitted because it is fixed at its 2020 value.

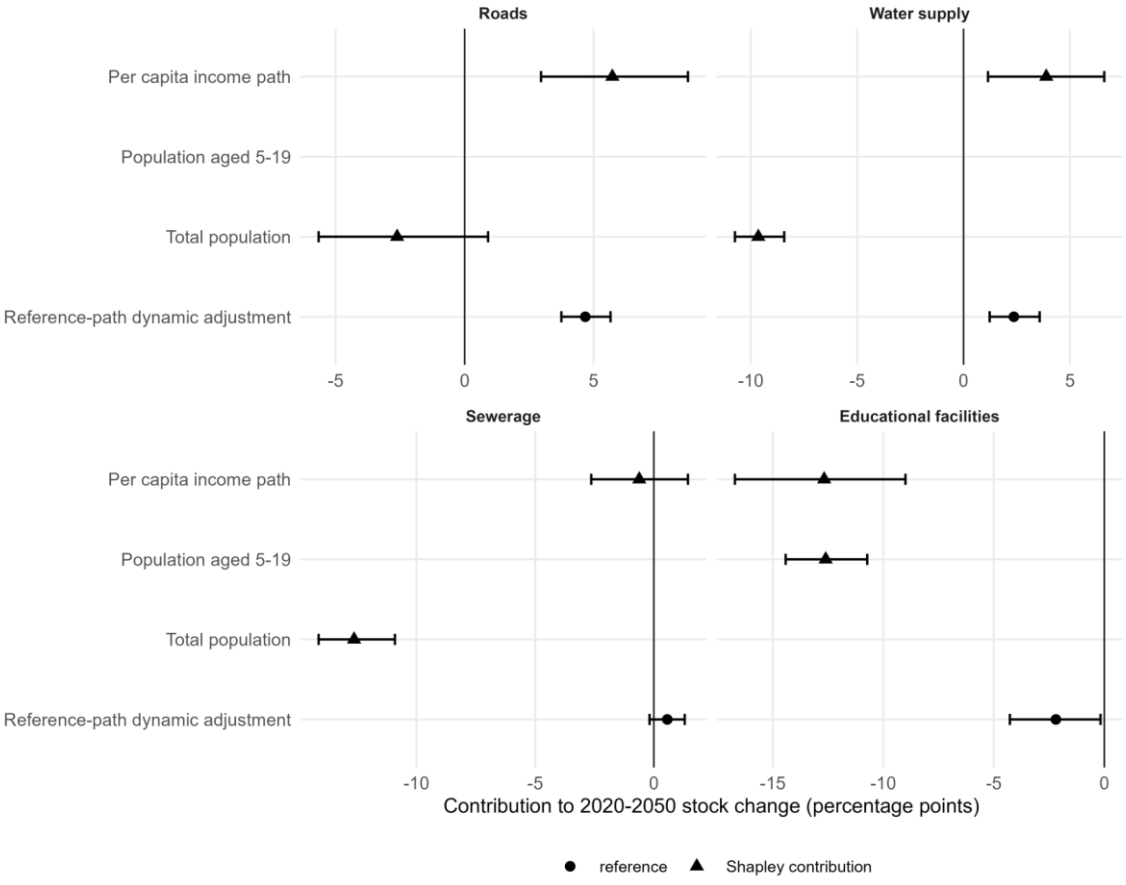


Figure 2: Model-implied contributions to 2020–2050 stock change
Notes: Points report posterior medians and horizontal bars report 95% credible intervals from Model 3. The

reference-path dynamic adjustment is the change generated when population, per capita income, and urbanization are held at their 2020 values. The remaining terms are Shapley contributions of future demographic and income paths, expressed as percentage-point contributions relative to observed 2020 stock. For educational facilities, the demographic path is population aged 5–19; for the other sectors it is total population. Urbanization is omitted because it is fixed at its 2020 value and therefore contributes zero by construction. The decomposition is model-based attribution and is not causal.

For roads, the median 7.8-percentage-point increase comprises a 4.68-point reference-path adjustment and a 5.73-point income contribution, partly offset by a -2.62-point population contribution. The 95% credible interval for the population contribution includes zero. The national increase is therefore not generated by population growth; it reflects upward adjustment under fixed 2020 covariates and the assumed income path. For water supply, the 2.37-point reference adjustment and 3.89-point income contribution are more than offset by a -9.65-point population contribution, yielding a net decline of 3.4 points. Population contraction is therefore the dominant force in the preferred water-supply forecast. Sewerage contraction is almost entirely demographic. The population path contributes -12.63 points, whereas the reference adjustment and income contribution are small and their intervals include zero. Among the four sectors, sewerage is the clearest example of population-driven stock adjustment. All three principal components lower the model-implied educational-facility stock: the reference adjustment contributes -2.19 points, the population aged 5–19 path -12.61 points, and the income path -12.67 points. The income contribution reflects extrapolation of a negative historical conditional relationship and should not be interpreted as a causal effect of income on socially desirable educational capacity.

6. Projected gross investment requirements

6.1 Annual gross investment requirements through 2050

Figure 3 compares observed real gross investment through 2020 with model-implied gross investment requirements from 2021. The historical series is the sum of real new and improvement expenditure and disaster-restoration expenditure. The forecast is the posterior median under Model 3 and the baseline income path.

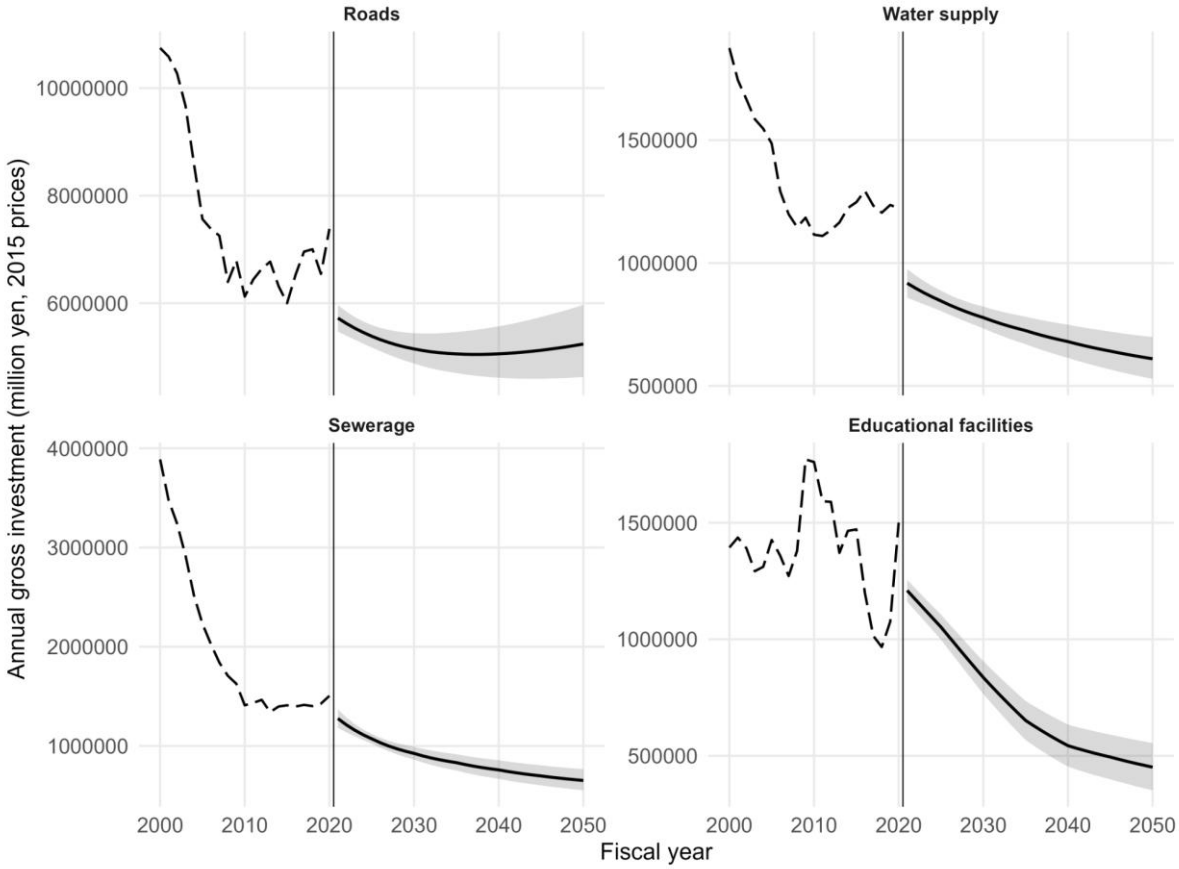


Figure 3: Observed real investment and projected annual gross investment requirements

Notes: Dashed lines show observed real gross investment through fiscal year 2020, defined as real new and improvement expenditure plus real disaster-restoration expenditure. Solid lines show posterior median model-implied gross investment requirements for 2021–2050, and shaded bands show 95% posterior credible intervals under Model 3 and the baseline income scenario. The vertical line separates observed and forecast periods. Monetary values are million yen per fiscal year at 2015 prices. Because the effective productive-capacity-loss rates are calibrated from the same stock-accounting system, the historical comparison is neither an independent validation exercise nor a funding-gap estimate.

Average observed investment over 2015–2019 was ¥6.61 trillion for roads, ¥1.24 trillion for water supply, ¥1.41 trillion for sewerage, and ¥1.15 trillion for educational facilities, or ¥10.41 trillion in total. The corresponding model-implied gross investment requirement in 2021 is ¥9.12 trillion. The difference is neither an investment surplus nor a shortfall: historical spending reflects budgets, timing, disasters, and policy choices, whereas the forecast is derived mechanically from the projected stock path and calibrated capacity losses.

Road investment falls from ¥5.72 trillion in 2021 to around ¥5.1 trillion during the 2030s before edging up to ¥5.24 trillion in 2050. The shallow U-shape is driven mainly by new expansion investment. As annual stock additions initially slow, total investment declines; later, the baseline income path and heterogeneous prefectural income slopes generate renewed expansion in some

prefectures. Water supply, sewerage, and educational-facility investment decline throughout most of the forecast. The mechanism is not only weaker expansion: as model-implied stocks contract, the productive-capacity base carried forward into subsequent periods also becomes smaller. Educational-facility investment falls especially sharply, from ¥1.21 trillion in 2021 to ¥0.45 trillion in 2050.

6.2 Shift toward sustaining capital

Figure 4 decomposes gross investment into new expansion and sustaining capital. New expansion is the positive annual increase in the model-implied stock. Sustaining capital restores productive capacity lost during the year, but only up to the level required by the current stock path. In addition, Table 5 summarizes the main national stock and investment projections, showing that population decline does not eliminate capital formation.

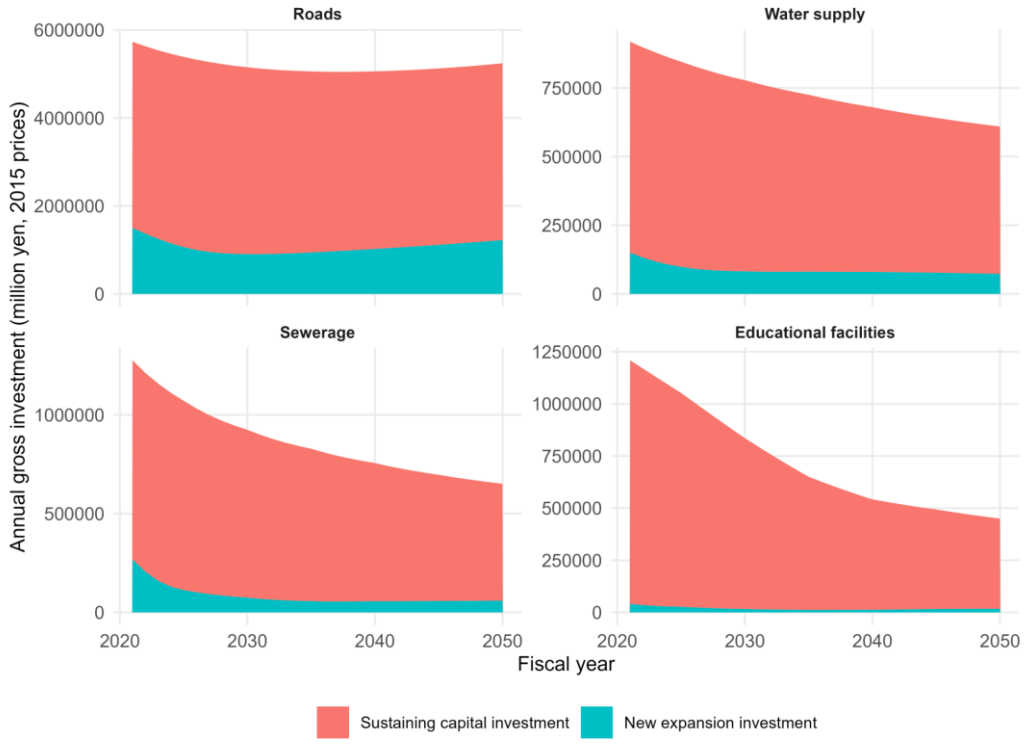


Figure 4: Annual gross investment requirements by component

Notes: Stacked areas show posterior median annual gross investment requirements under Model 3 and the baseline income scenario. New expansion investment is the positive annual increase in model-implied productive capital stock. Sustaining capital investment is the capital expenditure required to offset productive-capacity losses to the extent necessary to attain the current year's model-implied stock. It includes replacement and major capital rehabilitation but excludes routine operation, inspection, minor maintenance, and other current expenditure. Because medians are calculated component by component, their sum may differ slightly from the posterior median of total investment. Monetary values are million yen per fiscal year at 2015 prices.

Table 5: National forecast summary

Sector	Stock change, 2020-2050 (%)	Average annual gross investment, 2021-2050 (trillion yen)	Sustaining share in 2050 (%)
Roads	7.8 [4.6, 11.5]	5.20 [4.85, 5.60]	76.7 [72.4, 80.6]
Water supply	-3.4 [-5.8, -1.0]	0.73 [0.68, 0.79]	88.0 [81.5, 94.5]
Sewerage	-12.7 [-14.8, -10.4]	0.86 [0.79, 0.94]	90.8 [87.4, 93.5]
Educational facilities	-27.5 [-31.2, -23.9]	0.72 [0.65, 0.80]	96.1 [89.1, 100.0]

Notes: Entries report posterior medians with 95% credible intervals in brackets. Stock change is measured from observed 2020 stock to the 2050 baseline forecast. Average annual gross investment covers fiscal years 2021–2050 and is reported in trillion yen per year at 2015 prices. Credible intervals are conditional on the specified socioeconomic paths and baseline productive-capacity-loss rates.

For roads, 2021 gross investment of ¥5.72 trillion comprises ¥1.50 trillion of new expansion and ¥4.23 trillion of sustaining capital. Expansion falls to about ¥0.90 trillion around 2030 and then rises to ¥1.22 trillion in 2050. Total road investment is ¥5.24 trillion in 2050, of which 76.7% is sustaining capital. Water-supply investment declines from ¥0.92 trillion in 2021 to ¥0.61 trillion in 2050. New expansion falls from ¥0.15 trillion to ¥0.07 trillion and sustaining capital from ¥0.77 trillion to ¥0.54 trillion. Sustaining capital represents 88.0% of the 2050 total. Sewerage investment almost halves, from ¥1.28 trillion in 2021 to ¥0.65 trillion in 2050. New expansion declines from ¥0.27 trillion to ¥0.06 trillion, while sustaining capital falls from ¥1.01 trillion to ¥0.59 trillion. The 2050 sustaining share is 90.8%. Educational-facility expansion is only ¥0.04 trillion in 2021 and remains around ¥0.01–0.02 trillion after 2030. Gross investment is therefore almost entirely sustaining capital, with a 2050 share of 96.1%. Its absolute amount nevertheless falls because not all inherited capacity is renewed. The estimates exclude the potentially substantial short-run costs of consolidation, demolition, and conversion.

6.3 Model-implied contributions to average annual investment requirements

Figure 5 decomposes average annual gross investment over 2021–2050 into the fixed-covariate reference level and Shapley contributions from demographic and income paths. Complete results are reported in Table S6.

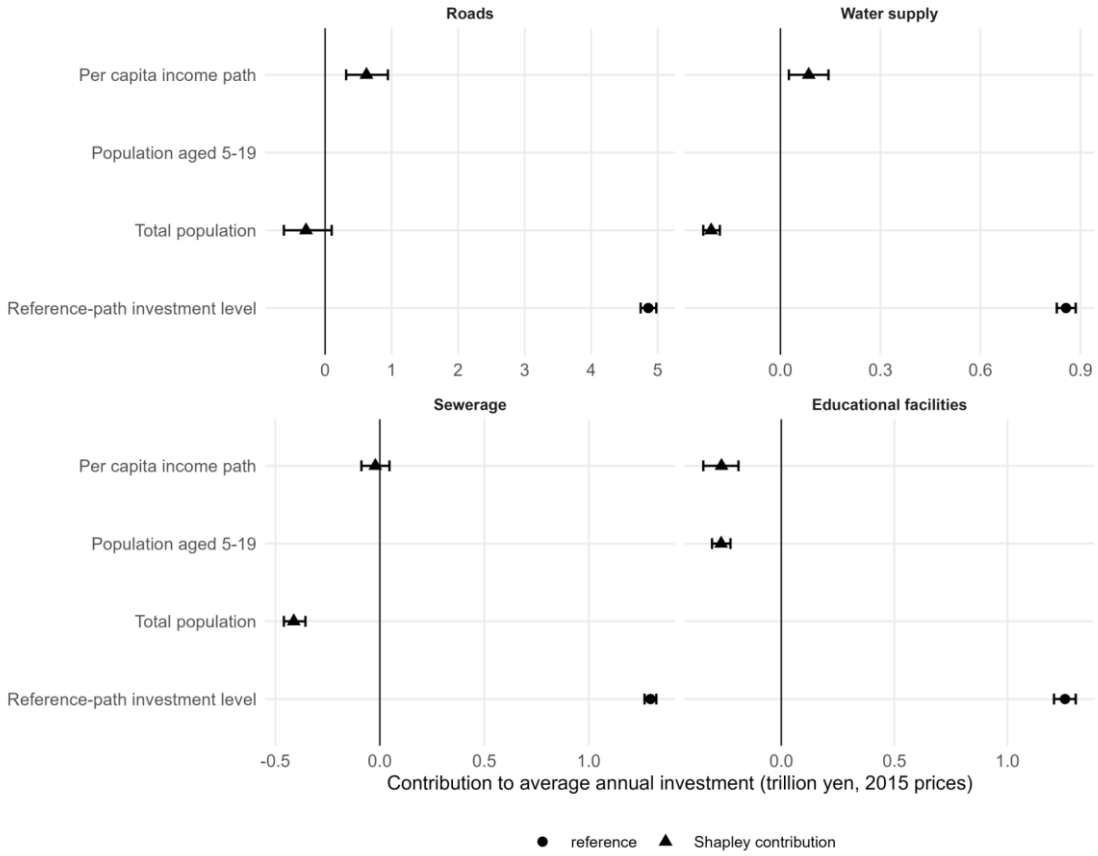


Figure 5: Model-implied contributions to average annual gross investment requirements

Notes: Points report posterior medians and horizontal bars report 95% credible intervals from Model 3. The reference-path investment level is the average annual investment requirement generated when population, per capita income, and urbanization are held at their 2020 values. The remaining terms are Shapley contributions of future demographic and income paths. Values are trillion yen per year at 2015 prices. Urbanization is omitted because it is held at its 2020 value and therefore contributes zero by construction. The decomposition is model-based attribution and is not causal.

Average annual road investment is ¥5.20 trillion [4.85, 5.60]. The reference-path level is ¥4.86 trillion, the income contribution is +¥0.62 trillion, and the population contribution is -¥0.29 trillion. The income contribution operates primarily through additional expansion rather than a uniform increase in sustaining capital. Average annual water-supply investment is ¥0.73 trillion [0.68, 0.79]. Relative to a reference level of ¥0.86 trillion, population contributes -¥0.21 trillion and income +¥0.09 trillion. Much of the demographic reduction occurs through a smaller sustaining-capital base. Average annual sewerage investment is ¥0.86 trillion [0.79, 0.94], compared with a reference level of ¥1.30 trillion. Population contributes -¥0.41 trillion. The net income contribution is small and uncertain because a modest positive contribution to expansion is offset by a negative contribution to sustaining capital. Average annual educational-facility investment is ¥0.72 trillion [0.65, 0.80], well below the ¥1.25 trillion reference level. Population

aged 5–19 contributes -¥0.27 trillion and income -¥0.26 trillion, almost entirely through lower sustaining capital. The results suggest that a central planning issue is which capacity to retain and reorganize rather than how to meet substantial new-construction demand.

6.4 Regional heterogeneity

National totals conceal wide prefectural variation. Table 6 and Figure 6 summarize the 2020–2050 stock adjustment, average investment burden relative to initial stock, sustaining shares, and geographic concentration of investment across the 47 prefectures. Complete prefecture-level results are reported in Table S8 and metropolitan/nonmetropolitan summaries in Table S9.

Table 6: Regional dispersion and concentration

Panel A. Prefecture stock-adjustment typology

Sector	Stock change: median [P10, P90] (%)	Expansion	Stable/uncertain	Contraction
Roads	4.1 [-8.4, 19.4]	21	16	10
Water supply	-7.2 [-18.0, 11.2]	7	7	33
Sewerage	-20.8 [-28.7, -6.6]	4	1	42
Educational facilities	-33.3 [-47.1, -21.0]	1	0	46

Panel B. Regional investment distribution

Sector	Top-10 share: total (%)	Top-10 share: expansion (%)	Average investment / 2021 stock: median [P10, P90] (%)	Sustaining share in 2050: median [P10, P90] (%)
Roads	46.5	70.0	1.70 [1.21, 2.28]	100.0 [72.1, 100.0]
Water supply	61.8	91.1	1.16 [0.73, 1.85]	100.0 [77.3, 100.0]
Sewerage	71.8	100.0	0.68 [0.38, 1.27]	100.0 [100.0, 100.0]
Educational facilities	60.7	100.0	1.22 [0.63, 1.74]	100.0 [100.0, 100.0]

Notes: Distributional statistics are calculated across the 47 prefectures using prefecture-level posterior medians under the baseline income scenario. Expansion denotes a posterior probability of stock increase of at least 0.80; contraction denotes a probability of no more than 0.20; remaining prefectures are classified as uncertain or broadly stable. Top-10 shares are based on average annual investment over 2021–2050. P10 and P90 are the 10th and 90th percentiles across prefectures.

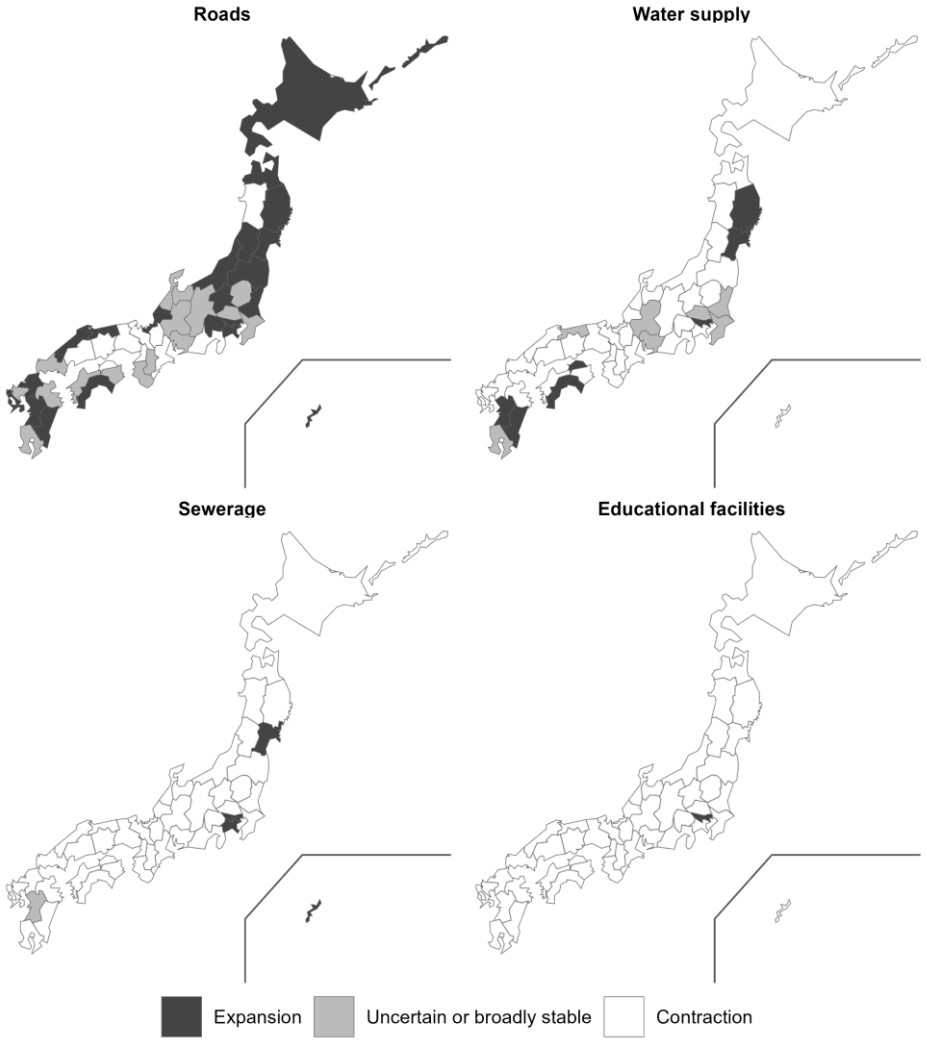


Figure 6: Prefecture typology of projected stock adjustment, 2020–2050

Notes: Maps classify each prefecture using the posterior probability that its model-implied productive capital stock increases between observed 2020 and the 2050 baseline forecast. Expansion indicates a probability of at least 0.80, contraction indicates a probability of no more than 0.20, and remaining prefectures are classified as uncertain or broadly stable. Results are based on Model 3 and the baseline income scenario.

The median prefectural road-stock change is 4.1%, with a P10–P90 range of -8.4% to 19.4%; 21 prefectures are classified as expansion, 16 as uncertain or broadly stable, and 10 as contraction. Water supply has a median change of -7.2%, but seven prefectures are classified as expansion. Sewerage contracts in 42 prefectures and educational facilities in 46. The latter two sectors therefore exhibit much broader regional contraction than roads. Miyagi, Iwate, and Kumamoto prefectures stand out as "expansion" classifications in multiple sectors. One possible explanation is that reconstruction-related capital accumulation during the estimation period is partly embedded in the estimated dynamics; the model cannot test this interpretation directly.

The median ratio of average annual investment to 2021 stock is 1.70% for roads, 1.16% for water supply, 0.68% for sewerage, and 1.22% for educational facilities. Total investment is concentrated: the top ten prefectures account for 46.5% of roads, 61.8% of water supply, 71.8% of sewerage, and 60.7% of educational-facility investment. Expansion is even more concentrated: the top ten prefectures account for 70.0% of road expansion, 91.1% of water-supply expansion, and 100% of sewerage and educational-facility expansion. The median prefecture has a 2050 sustaining share of 100% in every sector, even though the corresponding national shares are lower. This difference arises because the remaining expansion investment is concentrated in a relatively small number of prefectures.

7. Robustness and sensitivity

7.1 Robustness to model specification and estimation choices

Alternative models. The broad sectoral pattern is not an artifact of Model 3 alone. Roads remain above their 2020 stock under Models 1–3, with 2050 indices of 115.8, 105.7, and 107.8, whereas sewerage and educational facilities remain below 2020 under every model. Water supply is more specification-dependent: Model 1 implies an index of 105.0, while Models 2 and 3 imply 97.1 and 96.6.

Alternative estimation samples. Windows beginning in 1990 or 2005 and a sample ending in 2019 preserve road expansion and sewerage and educational-facility contraction, but the road index ranges from 105.3 to 125.2 and the 2005–2020 water specification implies 109.7. The preferred water result should therefore be described as near stability or moderate contraction under the main specification, not as a universally robust decline.

Education-age definitions. Replacing population aged 5–19 with ages 5–14 or 5–24 yields 2050 educational-facility indices of 72.1 and 74.2, compared with 72.5 in the preferred specification.

Prior specifications. Tighter and wider regularizing priors yield virtually identical long-horizon forecasts in all four sectors. Together, these checks indicate that the road direction and sewerage and educational contraction are fairly robust, whereas the magnitude of roads and the direction of water supply require more caution. Detailed results of all the above checks are reported in Table S10.

7.2 Sensitivity to forecast and stock-flow assumptions

Income-path sensitivity. Capping each prefecture's future real per capita income at its maximum observed over 2000–2020 lowers the median 2050 road stock by 4.85% and average road investment by 10.79% relative to the baseline. The corresponding effects for water supply are -2.60% and -7.37%; sewerage is essentially unchanged. Because the estimated educational income association is negative, the cap raises the 2050 educational stock by 8.70% and average

investment by 16.36%. The sectoral directions remain unchanged, but road and educational magnitudes are materially conditional on the income path (Table S11 and Figure S6).

Productive-capacity-loss sensitivity. Alternative loss-rate calibrations leave stock forecasts unchanged but alter investment levels. Across the deterministic alternatives, average annual investment ranges from ¥5.00–5.49 trillion for roads, ¥0.71–0.78 trillion for water supply, ¥0.82–1.04 trillion for sewerage, and ¥0.70–0.89 trillion for educational facilities. A nonparametric bootstrap of annual loss rates is also propagated through the investment conversion. The broad transition toward sustaining capital remains, but investment levels depend on the external calibration (Table S12).

8. Discussion

8.1 Population decline does not imply uniform infrastructure contraction

The first central finding is that demographic decline does not imply uniform contraction across infrastructure sectors. The preferred forecast combines moderate road expansion, near-term stability followed by modest water-supply contraction, and more pronounced contraction in sewerage and educational facilities. These differences reflect not only future population paths but also the position of observed 2020 stocks relative to conditional fixed points, income paths, sector-specific population relationships, and adjustment speeds.

For roads, the demographic contribution is negative rather than positive. The national increase arises from upward adjustment under fixed covariates and the assumed income path. Roads perform network, connectivity, logistics, and redundancy functions, but the model does not identify which of these mechanisms drives the forecast. Moreover, the size of the increase is sensitive to the estimation window and income extrapolation. Water supply is a boundary case. The preferred model implies modest contraction, but alternative models and samples range from contraction to expansion. By contrast, sewerage contraction is dominated by the population path and is comparatively robust. Educational-facility contraction is also robust to the age definition, although its magnitude depends partly on the negative conditional income relationship. Because these are long-lived assets, rapid demographic change translates into gradual stock adjustment, involving consolidation and conversion rather than an immediate one-for-one reduction in physical facilities.

8.2 From expansion to sustaining capital

The second central finding is a change in investment composition. Aggregate gross investment declines, but about four-fifths of the 2050 total is sustaining capital. The share is especially high in water supply, sewerage, and educational facilities, where new expansion becomes small or geographically concentrated. This distinction matters for fiscal interpretation. A stable stock still requires gross investment to replace productive capacity lost during the year. Conversely, when

the model-implied stock contracts, renewing the entire inherited stock would preserve capacity that is not carried forward into the model-implied stock path. Fiscal monitoring should therefore distinguish capital formation that expands capacity from investment that restores the service capacity of the productive capacity retained in the model-implied stock path.

8.3 Sectoral and regional reallocation pressures

The third central finding is that adjustment involves reallocation across sectors and regions, not merely a change in the national aggregate. A proportional reduction in every sector's budget would not match the projected pattern. Road expansion remains in parts of the country, whereas water supply, sewerage, and educational facilities face shrinking stock bases and rising sustaining shares. Medium-term capital planning should consider the direction of model-implied stock adjustment, the composition of gross investment, and the transition costs of consolidation separately rather than extrapolating historical sectoral shares.

Sectoral adjustment strategies need not map one-for-one from the estimated stock changes. Roads and water and sewerage systems are network assets, so connectivity and minimum-network requirements can make selective downsizing technically difficult and costly. Educational facilities are more discrete assets and may offer greater scope for consolidation or conversion as the relevant population declines. Similar percentage changes in model-implied stock may therefore imply quite different operational choices and transition costs across sectors.

Prefectural paths are also heterogeneous. National road expansion coexists with contractions in ten prefectures; water supply expands in only seven; and sewerage and educational-facility contraction is widespread. Because expansion is concentrated, the typical prefecture reaches a 100% sustaining share by 2050 even when the national share is lower.

These results suggest differentiated planning strategies. Growth centers may still require capacity additions, mature regions may focus on sustaining and rehabilitating existing networks, and rapidly shrinking regions may face model-implied capacity exit, requiring decisions about non-replacement, consolidation, conversion, or shared service areas. Smaller municipalities may face high planning and engineering burdens even when their stock declines, creating a potential role for national and prefectural governments in common asset information, technical support, and intermunicipal coordination. Capital plans should also be multiyear and permit resources to move as model-implied stock paths and investment composition diverge.

The forecasts do not impose fiscal constraints and therefore cannot determine which assets should be prioritized under a binding budget. They should instead be interpreted as one quantitative input into strategic asset-management decisions, in which service criticality, fiscal capacity, asset condition, distributional objectives, and the feasibility and transition costs of consolidation or

conversion must be considered jointly.

8.4 Broader applicability beyond Japan

The numerical estimates depend on Japanese institutions, stock accounting, service standards, and historical investment paths and should not be transferred directly to other countries. The framework itself is more portable: a hierarchical model can partially pool regional relationships, a stock-flow identity can connect capacity paths to annual capital formation, and sustaining investment can be adjusted when the model-implied stock contracts. It can be used to assess long-term investment trends at the national and sectoral levels even in countries where facility-level asset data are not yet fully developed, provided that regional stock data, population and income projections, and investment time series are available.

9. Limitations

Several limitations qualify the interpretation. First, the forecasts are conditional reduced-form benchmarks, not welfare-optimal or engineering-required stocks. Second, relationships estimated over 2000–2020 are extrapolated through 2050 without separately forecasting common macroeconomic shocks, technological change, or disaster-reconstruction dynamics. Third, official population paths, income scenarios, and fixed urbanization are treated as given, so the credible intervals are conditional rather than measures of full predictive uncertainty. Fourth, sector-specific national loss rates are applied uniformly across prefectures and over the forecast horizon. Although the historical productive-capital series already incorporates age-related retirement and efficiency decline, the forecast conversion does not explicitly model local asset-age distributions or cohort-specific retirement waves, including those associated with infrastructure built during Japan's high-growth era. Fifth, aggregate monetary stocks do not identify service quality, spatial access, or minimum network constraints of individual facilities. Sixth, investment requirements exclude transition costs associated with consolidation, demolition, conversion, and service-delivery redesign, which may be especially important in rapidly contracting regions.

10. Conclusion

This paper develops a subnational, stock-flow-consistent framework for forecasting infrastructure investment under population decline. Sector-specific Bayesian hierarchical dynamic models are estimated for Japan's 47 prefectures over 2000–2020 and projected through 2050. The resulting productive-capital paths are converted into annual gross investment using accounting-based sectoral loss rates, with explicit separation of new expansion, sustaining capital, and capacity exit.

The preferred specification implies a 7.8% increase in the model-implied national road-stock between observed 2020 and 2050, alongside declines of 3.4% for water supply, 12.7% for sewerage, and 27.5% for educational facilities. The road direction is fairly robust but its

magnitude is sensitive, water supply is specification-dependent, and sewerage and educational contraction are more stable. Aggregate gross investment declines from ¥9.12 trillion in 2021 to ¥6.95 trillion in 2050, while sustaining capital rises to about 80% of the total.

Population decline therefore does not imply the disappearance of public capital formation. The principal planning challenge is to reallocate fiscal and technical capacity among sectors and prefectures that continue to expand, those dominated by replacement and major rehabilitation, and those whose model-implied stock paths entail capacity exit and may therefore require non-replacement, consolidation, or conversion. Long-term infrastructure planning should reflect sectoral and regional changes in investment requirements integrate new expansion, sustaining capital consistent with the model-implied stock path, and infrastructure restructuring.

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Supplementary Material

Supplementary Tables

Table S1：Fixed-effects benchmark estimates

Panel A. Productive capital stock: prefecture fixed effects

Variable	Roads Productive	Water supply Productive	Sewerage Productive	Educational facilities Productive
Lagged dependent variable	0.887***	0.881***	0.834***	0.969***
	(0.011)	(0.011)	(0.012)	(0.019)
Population	-0.049	-0.011	0.109***	0.020***
	(0.029)	(0.027)	(0.028)	(0.006)
Per capita prefectural income	0.013	0.013	-0.007	-0.049***
	(0.008)	(0.009)	(0.016)	(0.010)
Urbanization rate	0.001	0.000	-0.001	-0.001*
	(0.001)	(0.001)	(0.001)	(0.000)
Observations	987	987	987	987
Within R-squared	0.994	0.990	0.989	0.952

Panel B. Net capital stock: prefecture fixed effects

Variable	Roads Net	Water supply Net	Sewerage Net	Educational facilities Net
Lagged dependent variable	0.876***	0.865***	0.824***	0.979***
	(0.012)	(0.012)	(0.013)	(0.015)
Population	-0.042	-0.006	0.166***	0.013*
	(0.031)	(0.028)	(0.037)	(0.007)
Per capita prefectural income	0.004	0.010	-0.028	-0.070***
	(0.009)	(0.011)	(0.021)	(0.011)
Urbanization rate	0.000	-0.000	-0.002*	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Observations	987	987	987	987
Within R-squared	0.989	0.981	0.972	0.935

Panel C. Productive capital stock: prefecture and year fixed effects

Variable	Roads Productive	Water supply Productive	Sewerage Productive	Educational facilities Productive
Lagged dependent variable	0.977***	0.910***	0.908***	0.951***
	(0.016)	(0.018)	(0.009)	(0.016)
Population	-0.003	0.011	0.114***	0.004
	(0.024)	(0.026)	(0.021)	(0.010)
Per capita prefectural income	0.028**	0.002	0.029	0.008
	(0.012)	(0.016)	(0.019)	(0.011)
Urbanization rate	0.001	-0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.000)
Observations	987	987	987	987
Within R-squared	0.969	0.940	0.973	0.933

Panel D. Net capital stock: prefecture and year fixed effects

Variable	Roads Net	Water supply Net	Sewerage Net	Educational facilities Net
Lagged dependent variable	0.982***	0.913***	0.912***	0.949***
	(0.017)	(0.019)	(0.010)	(0.015)
Population	-0.003	0.014	0.133***	0.008
	(0.026)	(0.030)	(0.022)	(0.013)
Per capita prefectural income	0.031**	0.002	0.034	0.005
	(0.013)	(0.017)	(0.021)	(0.013)
Urbanization rate	0.001	-0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Observations	987	987	987	987
Within R-squared	0.969	0.933	0.968	0.931

Panel E. Educational-facility population definitions

Variable	Productive: Ages 5-14	Net: Ages 5-14	Productive: Ages 5-19	Net: Ages 5-19	Productive: Ages 5-24	Net: Ages 5-24
Lagged dependent variable	0.968***	0.977***	0.969***	0.979***	0.968***	0.979***
	(0.018)	(0.015)	(0.019)	(0.015)	(0.019)	(0.015)
Population	0.025***	0.021**	0.020***	0.013*	0.015**	0.007
	(0.006)	(0.008)	(0.006)	(0.007)	(0.007)	(0.008)

Variable	Productive: Ages 5-14	Net: Ages 5-14	Productive: Ages 5-19	Net: Ages 5-19	Productive: Ages 5-24	Net: Ages 5-24
Per capita prefectural income	-0.044***	-0.064***	-0.049***	-0.070***	-0.049***	-0.073***
	(0.010)	(0.011)	(0.010)	(0.011)	(0.011)	(0.012)
Urbanization rate	-0.001*	-0.000	-0.001*	-0.001	-0.001*	-0.001
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Observations	987	987	987	987	987	987
Within R-squared	0.952	0.936	0.952	0.935	0.952	0.935

Panel F. Alternative estimation windows: productive capital stock

Variable	Main 2000-2020 | Roads	Main 2000-2020 | Water supply	Main 2000-2020 | Sewerage	Main 2000-2020 | Educational facilities	Earlier 1990-2020 | Roads	Earlier 1990-2020 | Water supply	Earlier 1990-2020 | Sewerage	Earlier 1990-2020 | Educational facilities	Exclude 2020 | Roads	Exclude 2020 | Water supply	Exclude 2020 | Sewerage	Exclude 2020 | Educational facilities	Later 2005-2020 | Roads	Later 2005-2020 | Water supply	Later 2005-2020 | Sewerage	Later 2005-2020 | Educational facilities
Lagged dependent variable	0.887***	0.881***	0.834***	0.969***	0.936***	0.936***	0.925***	0.967***	0.883***	0.877***	0.832***	0.971***	0.952***	0.923***	0.859***	0.960***
	(0.011)	(0.011)	(0.012)	(0.019)	(0.004)	(0.003)	(0.005)	(0.007)	(0.010)	(0.010)	(0.012)	(0.021)	(0.015)	(0.015)	(0.021)	(0.029)
Population	-0.049	-0.011	0.109***	0.020***	0.006	0.042**	0.142***	0.051***	-0.039	-0.002	0.113***	0.020***	-0.020	0.002	0.133***	0.018*
	(0.029)	(0.027)	(0.028)	(0.006)	(0.025)	(0.016)	(0.032)	(0.006)	(0.030)	(0.027)	(0.031)	(0.007)	(0.022)	(0.026)	(0.034)	(0.009)
Per capita prefectural income	0.013	0.013	-0.007	-0.049***	0.017	-0.003	-0.021	-0.019**	0.021**	0.023**	-0.005	-0.049***	0.010	0.012	-0.003	-0.062***
	(0.008)	(0.009)	(0.016)	(0.010)	(0.014)	(0.010)	(0.020)	(0.007)	(0.009)	(0.011)	(0.018)	(0.011)	(0.008)	(0.008)	(0.012)	(0.014)
Urbanization rate	0.001	0.000	-0.001	-0.001*	-0.000	-0.001**	-0.003***	-0.001*	0.001	-0.000	-0.001	-0.001*	0.000	0.000	-0.000	-0.001
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	987	987	987	987	1457	1457	1457	1457	940	940	940	940	752	752	752	752
Within R-squared	0.994	0.990	0.989	0.952	0.998	0.998	0.997	0.991	0.994	0.990	0.989	0.951	0.990	0.981	0.952	0.904

Notes: All models include prefecture fixed effects and standard errors clustered by prefecture. Panels C and D additionally include fiscal-year fixed effects. The lagged dependent variable in a short fixed-effects panel may be subject to Nickell bias; estimates are used as predictive benchmarks rather than causal parameters. Within R-squared is reported. Significance levels: *** p < 0.01; ** p < 0.05; * p < 0.10.

Table S2: Full Bayesian posterior estimates for Models 2 and 3

Parameter	Roads - M2	Roads - M3	Water supply - M2	Water supply - M3	Sewerage - M2	Sewerage - M3	Educational facilities - M2	Educational facilities - M3
Lagged stock	0.499 [0.495, 0.504]	0.494 [0.489, 0.498]	0.696 [0.690, 0.702]	0.695 [0.688, 0.701]	0.715 [0.709, 0.720]	0.708 [0.703, 0.713]	0.624 [0.619, 0.629]	0.625 [0.620, 0.630]
Per capita prefectural income	0.003 [0.001, 0.004]	0.002 [-0.002, 0.005]	0.002 [0.000, 0.004]	0.003 [-0.000, 0.006]	-0.001 [-0.003, 0.001]	0.000 [-0.004, 0.004]	-0.006 [-0.008, -0.005]	-0.008 [-0.010, -0.005]

Parameter	Roads - M2	Roads - M3	Water supply - M2	Water supply - M3	Sewerage - M2	Sewerage - M3	Educational facilities - M2	Educational facilities - M3
Population	0.015 [0.002, 0.026]	0.012 [-0.004, 0.025]	0.052 [0.044, 0.059]	0.056 [0.049, 0.062]	0.110 [0.097, 0.122]	0.113 [0.097, 0.127]	0.021 [0.017, 0.025]	0.020 [0.016, 0.024]
Urbanization rate	0.016 [0.008, 0.025]	0.024 [0.015, 0.032]	0.008 [0.001, 0.016]	0.007 [0.000, 0.015]	-0.013 [-0.022, -0.004]	-0.026 [-0.036, -0.017]	-0.005 [-0.009, -0.001]	-0.006 [-0.010, -0.003]
SD prefecture intercept	0.030 [0.022, 0.043]	0.036 [0.026, 0.052]	0.021 [0.016, 0.028]	0.018 [0.014, 0.023]	0.056 [0.044, 0.072]	0.067 [0.052, 0.090]	0.008 [0.006, 0.011]	0.006 [0.005, 0.009]
Residual SD	0.007 [0.007, 0.008]	0.006 [0.006, 0.006]	0.008 [0.007, 0.008]	0.007 [0.007, 0.007]	0.008 [0.008, 0.009]	0.007 [0.007, 0.007]	0.009 [0.008, 0.009]	0.009 [0.008, 0.009]
Corr(intercept, income slope)		0.116 [-0.212, 0.439]		-0.276 [-0.536, 0.029]		-0.344 [-0.577, -0.060]		-0.206 [-0.570, 0.214]

Notes: Entries report posterior medians with 95% credible intervals in brackets. Continuous predictors are standardized before estimation; the dependent variable remains in log levels. Model 2 includes prefecture-specific random intercepts, while Model 3 additionally allows prefecture-specific income coefficients.

Table S3: Original-scale persistence and half-lives

Sector	Model	Persistence: median [95%]	Pr(|phi| < 1)	Pr(0 < phi < 1)	Half-life: median [95%]
Roads	Model 2: random intercept	0.903 [0.895, 0.912]	1.000	1.000	6.8 [6.2, 7.5]
Roads	Model 3: random intercept + income slope	0.893 [0.885, 0.901]	1.000	1.000	6.1 [5.7, 6.6]
Water supply	Model 2: random intercept	0.905 [0.897, 0.913]	1.000	1.000	7.0 [6.4, 7.7]
Water supply	Model 3: random intercept + income slope	0.904 [0.896, 0.912]	1.000	1.000	6.8 [6.3, 7.5]
Sewerage	Model 2: random intercept	0.841 [0.834, 0.848]	1.000	1.000	4.0 [3.8, 4.2]
Sewerage	Model 3: random intercept + income slope	0.833 [0.827, 0.840]	1.000	1.000	3.8 [3.7, 4.0]
Educational facilities	Model 2: random intercept	0.976 [0.968, 0.984]	1.000	1.000	28.4 [21.2, 43.3]
Educational facilities	Model 3: random intercept + income slope	0.977 [0.969, 0.985]	1.000	1.000	29.3 [22.0, 44.6]

Notes: Persistence is the implied autoregressive coefficient on the original log-stock scale. Half-life is reported in years and is calculated only for stable positive persistence draws.

Table S4: MCMC diagnostics for Bayesian models

Sector	Model	Max. R-hat	Min. bulk ESS	Min. tail ESS	Divergences	Treedepth hits	Assessment
Roads	Model 2: random intercept	1.009	626	939	0	0	Good
Roads	Model 3: random intercept + income slope	1.003	1000	1881	0	0	Good
Water supply	Model 2: random intercept	1.008	970	1586	0	0	Good
Water supply	Model 3: random intercept + income slope	1.002	1426	2664	0	0	Good
Sewerage	Model 2: random intercept	1.010	678	916	0	0	Review
Sewerage	Model 3: random intercept + income slope	1.005	1286	2693	0	0	Good
Educational facilities	Model 2: random intercept	1.004	1589	3440	0	0	Good
Educational facilities	Model 3: random intercept + income slope	1.002	2219	4803	0	0	Good

Notes: R-hat denotes the potential scale reduction factor. Bulk and tail ESS are effective sample sizes for the central and tail regions of the posterior. Divergences and maximum-treedepth hits are counted after warmup.

Table S5: Detailed holdout performance and bootstrap comparisons

Panel A. Holdout metrics

Holdout	Sector	Model	Evaluation	RMSE	MAE	Mean error	Coverage 95%	Width 95%
2011-2020 ten-year	Educational facilities	Model 1: fixed effects	One-step-ahead	0.0103	0.0083	0.0035		
2011-2020 ten-year	Educational facilities	Model 1: fixed effects	Recursive	0.0398	0.0285	0.0070		
2011-2020 ten-year	Educational facilities	Model 2: random intercept	One-step-ahead	0.0120	0.0101	0.0078	0.923	0.0398
2011-2020 ten-year	Educational facilities	Model 2: random intercept	Recursive	0.0515	0.0373	0.0285	0.757	0.1007
2011-2020 ten-year	Educational facilities	Model 3: random intercept + income slope	One-step-ahead	0.0117	0.0098	0.0075	0.930	0.0400
2011-2020 ten-year	Educational facilities	Model 3: random intercept + income slope	Recursive	0.0500	0.0361	0.0270	0.794	0.1028
2011-2020 ten-year	Roads	Model 1: fixed effects	One-step-ahead	0.0157	0.0110	-0.0098		
2011-2020 ten-year	Roads	Model 1: fixed effects	Recursive	0.0569	0.0361	-0.0316		
2011-2020 ten-year	Roads	Model 2: random intercept	One-step-ahead	0.0173	0.0120	-0.0109	0.602	0.0230
2011-2020 ten-year	Roads	Model 2: random intercept	Recursive	0.0640	0.0402	-0.0356	0.491	0.0477
2011-2020 ten-year	Roads	Model 3: random intercept + income slope	One-step-ahead	0.0173	0.0120	-0.0110	0.632	0.0245
2011-2020 ten-year	Roads	Model 3: random intercept + income slope	Recursive	0.0639	0.0401	-0.0358	0.534	0.0574
2011-2020 ten-year	Sewerage	Model 1: fixed effects	One-step-ahead	0.0137	0.0093	-0.0020		
2011-2020 ten-year	Sewerage	Model 1: fixed effects	Recursive	0.0464	0.0292	-0.0033		
2011-2020 ten-year	Sewerage	Model 2: random intercept	One-step-ahead	0.0125	0.0093	-0.0013	0.913	0.0353
2011-2020 ten-year	Sewerage	Model 2: random intercept	Recursive	0.0427	0.0294	-0.0009	0.689	0.0681
2011-2020 ten-year	Sewerage	Model 3: random intercept + income slope	One-step-ahead	0.0117	0.0085	-0.0010	0.949	0.0369
2011-2020 ten-year	Sewerage	Model 3: random intercept + income slope	Recursive	0.0398	0.0270	-0.0001	0.802	0.0773
2011-2020 ten-year	Water supply	Model 1: fixed effects	One-step-ahead	0.0131	0.0102	-0.0090		
2011-2020 ten-year	Water supply	Model 1: fixed effects	Recursive	0.0454	0.0325	-0.0279		
2011-2020 ten-year	Water supply	Model 2: random intercept	One-step-ahead	0.0129	0.0097	-0.0078	0.815	0.0337
2011-2020 ten-year	Water supply	Model 2: random intercept	Recursive	0.0458	0.0312	-0.0244	0.709	0.0693
2011-2020 ten-year	Water supply	Model 3: random intercept + income slope	One-step-ahead	0.0124	0.0090	-0.0076	0.898	0.0364
2011-2020 ten-year	Water supply	Model 3: random intercept + income slope	Recursive	0.0429	0.0284	-0.0236	0.840	0.0872
2016-2020 five-year	Educational facilities	Model 1: fixed effects	One-step-ahead	0.0129	0.0117	0.0112		
2016-2020 five-year	Educational facilities	Model 1: fixed effects	Recursive	0.0373	0.0313	0.0308		
2016-2020 five-year	Educational facilities	Model 2: random intercept	One-step-ahead	0.0127	0.0115	0.0110	0.898	0.0362

Holdout	Sector	Model	Evaluation	RMSE	MAE	Mean error	Coverage 95%	Width 95%
2016-2020 five-year	Educational facilities	Model 2: random intercept	Recursive	0.0399	0.0339	0.0335	0.498	0.0631
2016-2020 five-year	Educational facilities	Model 3: random intercept + income slope	One-step-ahead	0.0123	0.0112	0.0107	0.919	0.0364
2016-2020 five-year	Educational facilities	Model 3: random intercept + income slope	Recursive	0.0387	0.0330	0.0327	0.532	0.0647
2016-2020 five-year	Roads	Model 1: fixed effects	One-step-ahead	0.0112	0.0072	-0.0044		
2016-2020 five-year	Roads	Model 1: fixed effects	Recursive	0.0294	0.0169	-0.0096		
2016-2020 five-year	Roads	Model 2: random intercept	One-step-ahead	0.0120	0.0079	-0.0055	0.847	0.0265
2016-2020 five-year	Roads	Model 2: random intercept	Recursive	0.0320	0.0189	-0.0123	0.770	0.0423
2016-2020 five-year	Roads	Model 3: random intercept + income slope	One-step-ahead	0.0098	0.0066	-0.0060	0.877	0.0258
2016-2020 five-year	Roads	Model 3: random intercept + income slope	Recursive	0.0244	0.0149	-0.0137	0.847	0.0462
2016-2020 five-year	Sewerage	Model 1: fixed effects	One-step-ahead	0.0107	0.0077	-0.0010		
2016-2020 five-year	Sewerage	Model 1: fixed effects	Recursive	0.0266	0.0176	-0.0014		
2016-2020 five-year	Sewerage	Model 2: random intercept	One-step-ahead	0.0108	0.0081	-0.0014	0.932	0.0337
2016-2020 five-year	Sewerage	Model 2: random intercept	Recursive	0.0270	0.0186	-0.0023	0.800	0.0507
2016-2020 five-year	Sewerage	Model 3: random intercept + income slope	One-step-ahead	0.0077	0.0055	-0.0029	0.945	0.0328
2016-2020 five-year	Sewerage	Model 3: random intercept + income slope	Recursive	0.0170	0.0112	-0.0055	0.923	0.0551
2016-2020 five-year	Water supply	Model 1: fixed effects	One-step-ahead	0.0095	0.0072	-0.0049		
2016-2020 five-year	Water supply	Model 1: fixed effects	Recursive	0.0232	0.0165	-0.0111		
2016-2020 five-year	Water supply	Model 2: random intercept	One-step-ahead	0.0103	0.0075	-0.0051	0.902	0.0311
2016-2020 five-year	Water supply	Model 2: random intercept	Recursive	0.0260	0.0175	-0.0119	0.766	0.0493
2016-2020 five-year	Water supply	Model 3: random intercept + income slope	One-step-ahead	0.0096	0.0071	-0.0054	0.928	0.0312
2016-2020 five-year	Water supply	Model 3: random intercept + income slope	Recursive	0.0233	0.0160	-0.0124	0.847	0.0541

Panel B. Prefecture-bootstrap differences in RMSE

Holdout	Sector	Evaluation	Comparison	Median difference	Lower 95%	Upper 95%	Pr(M3 lower RMSE)
2011-2020 ten-year	Educational facilities	One-step-ahead	Model 1: fixed effects minus M3	-0.0014	-0.0021	-0.0007	0.001
2011-2020 ten-year	Educational facilities	One-step-ahead	Model 2: random intercept minus M3	0.0003	0.0002	0.0003	1.000
2011-2020 ten-year	Educational facilities	Recursive	Model 1: fixed effects minus M3	-0.0104	-0.0148	-0.0051	0.000
2011-2020 ten-year	Educational facilities	Recursive	Model 2: random intercept minus M3	0.0015	0.0011	0.0019	1.000
2011-2020 ten-year	Roads	One-step-ahead	Model 1: fixed effects minus M3	-0.0016	-0.0024	-0.0006	0.000
2011-2020 ten-year	Roads	One-step-ahead	Model 2: random intercept minus M3	-0.0000	-0.0004	0.0004	0.477
2011-2020 ten-year	Roads	Recursive	Model 1: fixed effects minus M3	-0.0070	-0.0106	-0.0035	0.000
2011-2020 ten-year	Roads	Recursive	Model 2: random intercept minus M3	0.0001	-0.0014	0.0019	0.572
2011-2020 ten-year	Sewerage	One-step-ahead	Model 1: fixed effects minus M3	0.0020	0.0001	0.0035	0.978

Holdout	Sector	Evaluation	Comparison	Median difference	Lower 95%	Upper 95%	Pr(M3 lower RMSE)
2011-2020 ten-year	Sewerage	One-step-ahead	Model 2: random intercept minus M3	0.0008	0.0004	0.0014	1.000
2011-2020 ten-year	Sewerage	Recursive	Model 1: fixed effects minus M3	0.0066	0.0000	0.0119	0.975
2011-2020 ten-year	Sewerage	Recursive	Model 2: random intercept minus M3	0.0029	0.0014	0.0052	1.000
2011-2020 ten-year	Water supply	One-step-ahead	Model 1: fixed effects minus M3	0.0007	-0.0007	0.0026	0.810
2011-2020 ten-year	Water supply	One-step-ahead	Model 2: random intercept minus M3	0.0005	-0.0005	0.0018	0.828
2011-2020 ten-year	Water supply	Recursive	Model 1: fixed effects minus M3	0.0023	-0.0042	0.0105	0.758
2011-2020 ten-year	Water supply	Recursive	Model 2: random intercept minus M3	0.0027	-0.0018	0.0085	0.866
2016-2020 five-year	Educational facilities	One-step-ahead	Model 1: fixed effects minus M3	0.0006	0.0001	0.0010	0.997
2016-2020 five-year	Educational facilities	One-step-ahead	Model 2: random intercept minus M3	0.0004	0.0002	0.0006	1.000
2016-2020 five-year	Educational facilities	Recursive	Model 1: fixed effects minus M3	-0.0014	-0.0027	-0.0000	0.022
2016-2020 five-year	Educational facilities	Recursive	Model 2: random intercept minus M3	0.0013	0.0006	0.0018	1.000
2016-2020 five-year	Roads	One-step-ahead	Model 1: fixed effects minus M3	0.0013	-0.0011	0.0034	0.844
2016-2020 five-year	Roads	One-step-ahead	Model 2: random intercept minus M3	0.0021	0.0001	0.0041	0.990
2016-2020 five-year	Roads	Recursive	Model 1: fixed effects minus M3	0.0048	-0.0020	0.0108	0.917
2016-2020 five-year	Roads	Recursive	Model 2: random intercept minus M3	0.0074	0.0010	0.0130	0.996
2016-2020 five-year	Sewerage	One-step-ahead	Model 1: fixed effects minus M3	0.0028	0.0005	0.0057	0.995
2016-2020 five-year	Sewerage	One-step-ahead	Model 2: random intercept minus M3	0.0029	0.0012	0.0053	1.000
2016-2020 five-year	Sewerage	Recursive	Model 1: fixed effects minus M3	0.0091	0.0027	0.0164	1.000
2016-2020 five-year	Sewerage	Recursive	Model 2: random intercept minus M3	0.0097	0.0046	0.0157	1.000
2016-2020 five-year	Water supply	One-step-ahead	Model 1: fixed effects minus M3	-0.0001	-0.0010	0.0010	0.434
2016-2020 five-year	Water supply	One-step-ahead	Model 2: random intercept minus M3	0.0008	0.0000	0.0015	0.978
2016-2020 five-year	Water supply	Recursive	Model 1: fixed effects minus M3	-0.0001	-0.0028	0.0029	0.486
2016-2020 five-year	Water supply	Recursive	Model 2: random intercept minus M3	0.0027	0.0003	0.0051	0.987

Notes: Coverage and interval width are reported for Bayesian models only. Bootstrap differences are constructed by resampling prefectures; positive values for "comparison model minus M3" favor Model 3.

Table S6: Full Shapley decomposition results

Panel A. Contributions to 2020–2050 stock change

Sector	Term	Median	Lower 95%	Upper 95%
Roads	Reference-path dynamic adjustment	4.68	3.75	5.66
Roads	Total population	-2.62	-5.66	0.91
Roads	Per capita income path	5.73	2.96	8.66

Sector	Term	Median	Lower 95%	Upper 95%
Water supply	Reference-path dynamic adjustment	2.37	1.23	3.58
Water supply	Total population	-9.65	-10.75	-8.43
Water supply	Per capita income path	3.89	1.15	6.62
Sewerage	Reference-path dynamic adjustment	0.56	-0.18	1.30
Sewerage	Total population	-12.63	-14.12	-10.91
Sewerage	Per capita income path	-0.62	-2.64	1.44
Educational facilities	Reference-path dynamic adjustment	-2.19	-4.27	-0.17
Educational facilities	Population aged 5-19	-12.61	-14.42	-10.73
Educational facilities	Per capita income path	-12.67	-16.71	-9.00

Panel B. Contributions to average annual gross investment

Sector	Term	Median (trillion yen)	Lower 95% (trillion yen)	Upper 95% (trillion yen)
Roads	Reference-path investment level	4.859	4.744	4.980
Roads	Total population	-0.286	-0.620	0.099
Roads	Per capita income path	0.622	0.316	0.944
Water supply	Reference-path investment level	0.856	0.829	0.886
Water supply	Total population	-0.208	-0.231	-0.182
Water supply	Per capita income path	0.085	0.025	0.144
Sewerage	Reference-path investment level	1.296	1.267	1.324
Sewerage	Total population	-0.412	-0.459	-0.356
Sewerage	Per capita income path	-0.022	-0.088	0.046
Educational facilities	Reference-path investment level	1.254	1.206	1.302
Educational facilities	Population aged 5-19	-0.266	-0.306	-0.225
Educational facilities	Per capita income path	-0.264	-0.345	-0.189

Notes: Reference-path terms are not Shapley contributions. Demographic and income contributions are calculated within each posterior draw and are model-based attributions, not causal effects. Stock contributions are percentage points relative to observed 2020 stock; investment contributions are trillion yen per year at 2015 prices.

Table S7: Conditional fixed points under 2020 socioeconomic covariates

Sector	M2	M3
Roads	105.05 [103.82, 106.43]	104.84 [103.87, 105.89]
Water supply	103.34 [102.02, 104.82]	102.49 [101.29, 103.80]

Sector	M2	M3
Sewerage	101.08 [100.32, 101.82]	100.57 [99.82, 101.31]
Educational facilities	96.83 [92.59, 101.32]	96.43 [92.19, 100.70]

Notes: Entries report posterior median fixed-point indices with 95% credible intervals in brackets; observed 2020 national productive capital stock equals 100. Fixed points are mathematical convergence values and are not social optima, deficits, or policy targets.

Table S8: Prefecture-level stock adjustment and investment indicators

Panel: Roads

Prefecture	Typology	Pr(increase)	Stock change median [95%] (%)	Metro group	Average investment / 2021 stock (%)	Sustaining share 2050 (%)	Pr(new > 0 in 2050)
Hokkaido	Expansion	0.888	10.8 [-6.1, 30.1]	Non-metropolitan	1.95	83.2	0.781
Aomori	Expansion	0.823	5.0 [-5.3, 16.0]	Non-metropolitan	1.73	100.0	0.498
Iwate	Expansion	1.000	122.1 [95.4, 152.9]	Non-metropolitan	6.19	31.4	1.000
Miyagi	Expansion	1.000	86.0 [62.7, 112.7]	Non-metropolitan	4.83	37.2	1.000
Akita	Contraction	0.141	-6.6 [-17.7, 5.7]	Non-metropolitan	1.27	100.0	0.029
Yamagata	Expansion	0.977	16.8 [0.2, 35.4]	Non-metropolitan	2.19	80.8	0.906
Fukushima	Expansion	0.999	19.1 [6.4, 33.1]	Non-metropolitan	2.27	70.3	0.998
Ibaraki	Expansion	0.995	18.4 [4.2, 34.7]	Non-metropolitan	2.25	74.2	0.975
Tochigi	Uncertain or broadly stable	0.229	-3.5 [-12.0, 5.8]	Non-metropolitan	1.40	100.0	0.013
Gunma	Expansion	0.836	6.0 [-5.5, 18.6]	Non-metropolitan	1.76	90.1	0.726
Saitama	Uncertain or broadly stable	0.375	-1.5 [-10.6, 8.1]	Metropolitan	1.47	100.0	0.083
Chiba	Uncertain or broadly stable	0.634	1.2 [-5.3, 7.7]	Metropolitan	1.59	100.0	0.037
Tokyo	Expansion	0.963	7.5 [-0.7, 16.5]	Metropolitan	1.81	82.9	0.917
Kanagawa	Expansion	0.955	4.3 [-0.6, 9.9]	Metropolitan	1.70	99.9	0.516
Niigata	Expansion	0.919	9.0 [-3.6, 22.7]	Non-metropolitan	1.88	85.6	0.827
Toyama	Uncertain or broadly stable	0.679	2.9 [-8.8, 16.0]	Non-metropolitan	1.65	100.0	0.393
Ishikawa	Uncertain or broadly stable	0.745	4.3 [-7.8, 18.0]	Non-metropolitan	1.71	100.0	0.403
Fukui	Expansion	0.990	21.2 [2.9, 42.8]	Non-metropolitan	2.36	73.2	0.959
Yamanashi	Expansion	1.000	35.2 [19.3, 52.3]	Non-metropolitan	2.90	59.5	1.000
Nagano	Uncertain or broadly stable	0.659	2.0 [-7.0, 11.8]	Non-metropolitan	1.60	100.0	0.490
Gifu	Uncertain or broadly stable	0.747	5.7 [-10.1, 23.4]	Metropolitan	1.75	98.0	0.536
Shizuoka	Contraction	0.027	-9.8 [-18.8, 0.2]	Non-metropolitan	1.17	100.0	0.000
Aichi	Uncertain or broadly stable	0.505	0.0 [-7.0, 7.4]	Metropolitan	1.54	100.0	0.049

Prefecture	Typology	Pr(increase)	Stock change median [95%] (%)	Metro group	Average investment / 2021 stock (%)	Sustaining share 2050 (%)	Pr(new > 0 in 2050)
Mie	Contraction	0.109	-5.0 [-12.2, 2.9]	Metropolitan	1.33	100.0	0.007
Shiga	Contraction	0.094	-7.5 [-17.7, 3.8]	Non-metropolitan	1.26	100.0	0.002
Kyoto	Contraction	0.004	-12.1 [-20.5, -3.2]	Metropolitan	1.07	100.0	0.000
Osaka	Contraction	0.036	-8.0 [-16.3, 0.8]	Metropolitan	1.22	100.0	0.005
Hyogo	Contraction	0.008	-11.2 [-19.5, -2.2]	Metropolitan	1.09	100.0	0.000
Nara	Uncertain or broadly stable	0.672	2.1 [-6.7, 11.2]	Metropolitan	1.62	100.0	0.090
Wakayama	Uncertain or broadly stable	0.690	1.6 [-4.5, 8.4]	Non-metropolitan	1.55	79.2	0.994
Tottori	Expansion	0.964	16.2 [-1.3, 37.4]	Non-metropolitan	2.17	78.4	0.884
Shimane	Expansion	0.967	16.2 [-1.1, 35.2]	Non-metropolitan	2.16	77.4	0.908
Okayama	Contraction	0.047	-9.7 [-19.9, 1.7]	Non-metropolitan	1.16	100.0	0.003
Hiroshima	Contraction	0.162	-5.4 [-15.7, 5.7]	Non-metropolitan	1.32	100.0	0.038
Yamaguchi	Uncertain or broadly stable	0.246	-2.5 [-9.1, 4.8]	Non-metropolitan	1.44	100.0	0.008
Tokushima	Uncertain or broadly stable	0.287	-3.7 [-15.6, 9.1]	Non-metropolitan	1.38	100.0	0.110
Kagawa	Contraction	0.143	-8.9 [-23.1, 8.0]	Non-metropolitan	1.18	100.0	0.067
Ehime	Uncertain or broadly stable	0.302	-2.6 [-11.5, 7.3]	Non-metropolitan	1.44	100.0	0.047
Kochi	Expansion	0.991	19.8 [3.0, 39.0]	Non-metropolitan	2.29	68.0	0.983
Fukuoka	Expansion	0.962	4.1 [-0.4, 8.7]	Non-metropolitan	1.70	100.0	0.221
Saga	Uncertain or broadly stable	0.740	3.9 [-7.4, 16.4]	Non-metropolitan	1.69	100.0	0.335
Nagasaki	Expansion	0.809	5.0 [-5.9, 16.7]	Non-metropolitan	1.72	98.3	0.552
Kumamoto	Expansion	0.992	17.4 [3.2, 33.9]	Non-metropolitan	2.21	76.9	0.961
Oita	Uncertain or broadly stable	0.622	1.6 [-8.3, 12.2]	Non-metropolitan	1.60	100.0	0.210
Miyazaki	Expansion	0.965	15.8 [-1.1, 34.9]	Non-metropolitan	2.15	75.7	0.921
Kagoshima	Uncertain or broadly stable	0.768	6.0 [-9.0, 23.0]	Non-metropolitan	1.77	95.6	0.582
Okinawa	Expansion	0.995	15.6 [3.8, 28.3]	Non-metropolitan	2.15	81.2	0.934

Panel: Water supply

Prefecture	Typology	Pr(increase)	Stock change median [95%] (%)	Metro group	Average investment / 2021 stock (%)	Sustaining share 2050 (%)	Pr(new > 0 in 2050)
Hokkaido	Contraction	0.063	-12.7 [-26.7, 4.2]	Non-metropolitan	0.94	100.0	0.040
Aomori	Contraction	0.000	-18.6 [-27.1, -9.0]	Non-metropolitan	0.70	100.0	0.000
Iwate	Expansion	0.897	10.6 [-5.6, 29.3]	Non-metropolitan	1.84	80.5	0.862
Miyagi	Expansion	0.985	19.6 [1.8, 40.3]	Non-metropolitan	2.19	69.5	0.964

Prefecture	Typology	Pr(increase)	Stock change median [95%] (%)	Metro group	Average investment / 2021 stock (%)	Sustaining share 2050 (%)	Pr(new > 0 in 2050)
Akita	Contraction	0.004	-17.4 [-28.6, -4.7]	Non-metropolitan	0.75	100.0	0.000
Yamagata	Contraction	0.076	-12.5 [-27.5, 5.3]	Non-metropolitan	0.94	100.0	0.020
Fukushima	Contraction	0.004	-17.7 [-28.6, -5.6]	Non-metropolitan	0.74	100.0	0.000
Ibaraki	Uncertain or broadly stable	0.204	-6.3 [-20.0, 9.7]	Non-metropolitan	1.20	100.0	0.045
Tochigi	Contraction	0.008	-12.6 [-21.8, -2.6]	Non-metropolitan	0.95	100.0	0.000
Gunma	Contraction	0.104	-8.5 [-20.3, 5.2]	Non-metropolitan	1.11	100.0	0.040
Saitama	Uncertain or broadly stable	0.309	-2.7 [-13.5, 8.9]	Metropolitan	1.34	100.0	0.031
Chiba	Uncertain or broadly stable	0.520	0.2 [-6.9, 7.9]	Metropolitan	1.44	100.0	0.190
Tokyo	Expansion	1.000	19.0 [9.4, 29.5]	Metropolitan	2.17	73.9	0.985
Kanagawa	Contraction	0.150	-3.2 [-8.9, 2.9]	Metropolitan	1.31	100.0	0.000
Niigata	Contraction	0.146	-7.2 [-19.2, 6.8]	Non-metropolitan	1.14	100.0	0.131
Toyama	Contraction	0.026	-12.3 [-23.2, 0.1]	Non-metropolitan	0.95	100.0	0.012
Ishikawa	Contraction	0.130	-7.5 [-19.6, 6.1]	Non-metropolitan	1.14	100.0	0.060
Fukui	Contraction	0.000	-38.7 [-50.2, -24.9]	Non-metropolitan	0.18	100.0	0.000
Yamanashi	Contraction	0.024	-14.2 [-26.9, -0.3]	Non-metropolitan	0.88	100.0	0.001
Nagano	Contraction	0.001	-16.8 [-25.9, -6.8]	Non-metropolitan	0.77	100.0	0.000
Gifu	Uncertain or broadly stable	0.484	-0.4 [-17.5, 19.7]	Metropolitan	1.42	100.0	0.304
Shizuoka	Contraction	0.149	-6.3 [-17.1, 6.1]	Non-metropolitan	1.18	100.0	0.104
Aichi	Uncertain or broadly stable	0.326	-2.1 [-10.1, 6.9]	Metropolitan	1.36	100.0	0.069
Mie	Contraction	0.000	-24.6 [-31.2, -17.5]	Metropolitan	0.47	100.0	0.000
Shiga	Contraction	0.014	-14.3 [-25.5, -1.7]	Non-metropolitan	0.90	100.0	0.000
Kyoto	Contraction	0.086	-7.3 [-17.0, 3.5]	Metropolitan	1.16	100.0	0.013
Osaka	Contraction	0.089	-6.9 [-16.2, 3.4]	Metropolitan	1.17	100.0	0.027
Hyogo	Contraction	0.001	-16.0 [-24.9, -6.1]	Metropolitan	0.81	100.0	0.000
Nara	Contraction	0.000	-18.8 [-26.0, -11.4]	Metropolitan	0.69	100.0	0.000
Wakayama	Contraction	0.000	-16.0 [-20.0, -11.6]	Non-metropolitan	0.78	100.0	0.000
Tottori	Uncertain or broadly stable	0.376	-3.0 [-19.8, 16.9]	Non-metropolitan	1.32	100.0	0.180
Shimane	Contraction	0.053	-14.5 [-29.7, 3.5]	Non-metropolitan	0.87	100.0	0.016
Okayama	Contraction	0.186	-6.1 [-18.7, 8.0]	Non-metropolitan	1.20	100.0	0.079
Hiroshima	Contraction	0.135	-7.1 [-18.6, 5.8]	Non-metropolitan	1.16	100.0	0.072
Yamaguchi	Contraction	0.000	-17.1 [-22.3, -11.5]	Non-metropolitan	0.75	100.0	0.000
Tokushima	Contraction	0.076	-10.6 [-23.3, 3.9]	Non-metropolitan	1.02	100.0	0.013
Kagawa	Expansion	0.952	18.2 [-2.8, 44.8]	Non-metropolitan	2.12	63.4	0.952

Prefecture	Typology	Pr(increase)	Stock change median [95%] (%)	Metro group	Average investment / 2021 stock (%)	Sustaining share 2050 (%)	Pr(new > 0 in 2050)
Ehime	Contraction	0.149	-5.2 [-14.2, 5.0]	Non-metropolitan	1.21	100.0	0.224
Kochi	Expansion	0.887	11.1 [-6.4, 32.5]	Non-metropolitan	1.84	69.7	0.944
Fukuoka	Contraction	0.178	-2.4 [-7.1, 2.7]	Non-metropolitan	1.35	100.0	0.000
Saga	Contraction	0.144	-6.6 [-18.1, 6.3]	Non-metropolitan	1.17	100.0	0.066
Nagasaki	Contraction	0.049	-9.7 [-19.9, 1.9]	Non-metropolitan	1.05	100.0	0.004
Kumamoto	Expansion	0.998	25.7 [7.3, 46.5]	Non-metropolitan	2.44	66.2	0.990
Oita	Contraction	0.105	-6.8 [-16.8, 4.3]	Non-metropolitan	1.17	100.0	0.021
Miyazaki	Expansion	0.891	11.4 [-6.1, 32.7]	Non-metropolitan	1.87	79.5	0.830
Kagoshima	Uncertain or broadly stable	0.601	2.3 [-13.7, 21.9]	Non-metropolitan	1.52	100.0	0.495
Okinawa	Contraction	0.001	-19.2 [-28.7, -8.7]	Non-metropolitan	0.72	100.0	0.000

Panel: Sewerage

Prefecture	Typology	Pr(increase)	Stock change median [95%] (%)	Metro group	Average investment / 2021 stock (%)	Sustaining share 2050 (%)	Pr(new > 0 in 2050)
Hokkaido	Contraction	0.000	-20.8 [-30.8, -9.3]	Non-metropolitan	0.70	100.0	0.000
Aomori	Contraction	0.000	-29.2 [-35.1, -23.0]	Non-metropolitan	0.35	100.0	0.000
Iwate	Contraction	0.000	-19.6 [-28.3, -10.3]	Non-metropolitan	0.73	100.0	0.000
Miyagi	Expansion	1.000	54.0 [36.7, 73.1]	Non-metropolitan	3.64	44.7	1.000
Akita	Contraction	0.000	-32.8 [-39.3, -25.6]	Non-metropolitan	0.20	100.0	0.000
Yamagata	Contraction	0.000	-21.9 [-31.2, -11.4]	Non-metropolitan	0.64	100.0	0.000
Fukushima	Contraction	0.000	-21.5 [-28.9, -13.2]	Non-metropolitan	0.66	100.0	0.000
Ibaraki	Contraction	0.016	-11.4 [-20.9, -1.0]	Non-metropolitan	1.07	100.0	0.012
Tochigi	Contraction	0.000	-24.5 [-30.5, -18.1]	Non-metropolitan	0.55	100.0	0.000
Gunma	Contraction	0.000	-17.5 [-25.3, -9.0]	Non-metropolitan	0.84	100.0	0.000
Saitama	Contraction	0.000	-16.0 [-22.4, -9.1]	Metropolitan	0.91	100.0	0.000
Chiba	Contraction	0.001	-8.3 [-13.0, -3.4]	Metropolitan	1.21	100.0	0.000
Tokyo	Expansion	0.879	4.6 [-3.0, 12.8]	Metropolitan	1.74	100.0	0.135
Kanagawa	Expansion	0.991	5.0 [0.8, 9.3]	Metropolitan	1.76	100.0	0.000
Niigata	Contraction	0.000	-20.8 [-28.7, -11.9]	Non-metropolitan	0.68	100.0	0.000
Toyama	Contraction	0.000	-23.5 [-31.2, -15.2]	Non-metropolitan	0.58	100.0	0.000
Ishikawa	Contraction	0.000	-22.8 [-30.5, -14.2]	Non-metropolitan	0.63	100.0	0.000
Fukui	Contraction	0.002	-18.3 [-29.0, -6.3]	Non-metropolitan	0.79	100.0	0.000

Prefecture	Typology	Pr(increase)	Stock change median [95%] (%)	Metro group	Average investment / 2021 stock (%)	Sustaining share 2050 (%)	Pr(new > 0 in 2050)
Yamanashi	Contraction	0.000	-31.8 [-38.6, -24.4]	Non-metropolitan	0.25	100.0	0.000
Nagano	Contraction	0.000	-35.1 [-40.2, -29.6]	Non-metropolitan	0.18	100.0	0.000
Gifu	Contraction	0.000	-32.7 [-41.2, -23.0]	Metropolitan	0.25	100.0	0.000
Shizuoka	Contraction	0.000	-19.7 [-26.6, -12.0]	Non-metropolitan	0.74	100.0	0.000
Aichi	Contraction	0.004	-8.2 [-14.0, -2.1]	Metropolitan	1.21	100.0	0.001
Mie	Contraction	0.000	-17.9 [-23.2, -12.3]	Metropolitan	0.81	100.0	0.000
Shiga	Contraction	0.000	-25.5 [-32.7, -17.6]	Non-metropolitan	0.53	100.0	0.000
Kyoto	Contraction	0.000	-22.3 [-28.4, -15.8]	Metropolitan	0.66	100.0	0.000
Osaka	Contraction	0.000	-19.8 [-26.0, -13.2]	Metropolitan	0.77	100.0	0.000
Hyogo	Contraction	0.000	-24.1 [-30.0, -17.5]	Metropolitan	0.57	100.0	0.000
Nara	Contraction	0.000	-25.0 [-30.1, -19.7]	Metropolitan	0.52	100.0	0.000
Wakayama	Contraction	0.000	-26.5 [-30.2, -22.3]	Non-metropolitan	0.44	100.0	0.000
Tottori	Contraction	0.000	-28.3 [-37.8, -17.2]	Non-metropolitan	0.39	100.0	0.000
Shimane	Contraction	0.000	-27.7 [-36.8, -17.5]	Non-metropolitan	0.41	100.0	0.000
Okayama	Contraction	0.000	-20.8 [-28.7, -12.3]	Non-metropolitan	0.70	100.0	0.000
Hiroshima	Contraction	0.000	-20.8 [-28.1, -12.8]	Non-metropolitan	0.70	100.0	0.000
Yamaguchi	Contraction	0.000	-25.9 [-30.0, -21.4]	Non-metropolitan	0.46	100.0	0.000
Tokushima	Contraction	0.003	-14.3 [-23.5, -4.4]	Non-metropolitan	0.96	100.0	0.000
Kagawa	Contraction	0.005	-17.2 [-28.5, -4.3]	Non-metropolitan	0.84	100.0	0.008
Ehime	Contraction	0.000	-23.3 [-29.3, -16.7]	Non-metropolitan	0.58	100.0	0.000
Kochi	Contraction	0.000	-21.0 [-30.4, -10.3]	Non-metropolitan	0.68	100.0	0.000
Fukuoka	Contraction	0.000	-8.9 [-12.3, -5.5]	Non-metropolitan	1.17	100.0	0.000
Saga	Contraction	0.017	-10.1 [-18.7, -0.7]	Non-metropolitan	1.11	100.0	0.061
Nagasaki	Contraction	0.000	-21.4 [-28.0, -14.2]	Non-metropolitan	0.67	100.0	0.000
Kumamoto	Uncertain or broadly stable	0.228	-4.1 [-14.3, 7.1]	Non-metropolitan	1.36	100.0	0.195
Oita	Contraction	0.000	-21.4 [-28.0, -14.4]	Non-metropolitan	0.67	100.0	0.000
Miyazaki	Contraction	0.000	-23.9 [-33.5, -13.0]	Non-metropolitan	0.57	100.0	0.000
Kagoshima	Contraction	0.002	-17.1 [-27.3, -5.7]	Non-metropolitan	0.84	100.0	0.002
Okinawa	Expansion	0.991	11.3 [1.8, 21.9]	Non-metropolitan	1.98	85.2	0.934

Panel: Educational facilities

Prefecture	Typology	Pr(increase)	Stock change median [95%] (%)	Metro group	Average investment / 2021 stock (%)	Sustaining share 2050 (%)	Pr(new > 0 in 2050)
Hokkaido	Contraction	0.000	-40.8 [-52.7, -26.3]	Non-metropolitan	0.85	100.0	0.000
Aomori	Contraction	0.000	-44.4 [-54.5, -32.3]	Non-metropolitan	0.67	100.0	0.000
Iwate	Contraction	0.000	-45.8 [-59.0, -29.0]	Non-metropolitan	0.62	100.0	0.000
Miyagi	Contraction	0.081	-19.6 [-39.8, 9.8]	Non-metropolitan	1.80	100.0	0.142
Akita	Contraction	0.000	-51.8 [-62.7, -38.5]	Non-metropolitan	0.46	100.0	0.000
Yamagata	Contraction	0.000	-45.7 [-61.5, -23.3]	Non-metropolitan	0.63	100.0	0.000
Fukushima	Contraction	0.007	-28.5 [-44.9, -6.0]	Non-metropolitan	1.39	100.0	0.020
Ibaraki	Contraction	0.001	-36.8 [-52.1, -17.5]	Non-metropolitan	1.05	100.0	0.001
Tochigi	Contraction	0.000	-39.1 [-50.7, -25.6]	Non-metropolitan	0.93	100.0	0.000
Gunma	Contraction	0.000	-40.0 [-52.2, -25.5]	Non-metropolitan	0.94	100.0	0.000
Saitama	Contraction	0.000	-37.7 [-50.2, -23.8]	Metropolitan	0.99	100.0	0.000
Chiba	Contraction	0.000	-21.9 [-31.2, -11.9]	Metropolitan	1.71	100.0	0.001
Tokyo	Expansion	0.909	8.4 [-3.8, 21.9]	Metropolitan	3.05	89.7	0.844
Kanagawa	Contraction	0.035	-9.5 [-18.8, 0.9]	Metropolitan	2.25	100.0	0.021
Niigata	Contraction	0.000	-39.8 [-51.8, -26.7]	Non-metropolitan	0.92	100.0	0.000
Toyama	Contraction	0.000	-31.8 [-44.8, -16.7]	Non-metropolitan	1.29	100.0	0.000
Ishikawa	Contraction	0.001	-30.2 [-44.5, -13.9]	Non-metropolitan	1.40	100.0	0.000
Fukui	Contraction	0.000	-49.2 [-64.8, -29.2]	Non-metropolitan	0.55	100.0	0.000
Yamanashi	Contraction	0.000	-51.1 [-64.2, -34.8]	Non-metropolitan	0.48	100.0	0.000
Nagano	Contraction	0.000	-32.7 [-45.9, -16.6]	Non-metropolitan	1.22	100.0	0.000
Gifu	Contraction	0.000	-49.3 [-63.9, -33.0]	Metropolitan	0.60	100.0	0.000
Shizuoka	Contraction	0.000	-42.1 [-53.6, -29.6]	Non-metropolitan	0.85	100.0	0.000
Aichi	Contraction	0.000	-24.4 [-34.8, -12.6]	Metropolitan	1.61	100.0	0.000
Mie	Contraction	0.000	-30.8 [-41.9, -17.6]	Metropolitan	1.31	100.0	0.000
Shiga	Contraction	0.001	-31.2 [-45.6, -14.2]	Non-metropolitan	1.30	100.0	0.001
Kyoto	Contraction	0.000	-31.5 [-43.4, -18.1]	Metropolitan	1.31	100.0	0.000
Osaka	Contraction	0.000	-37.0 [-47.0, -26.7]	Metropolitan	1.02	100.0	0.000
Hyogo	Contraction	0.000	-33.4 [-45.2, -19.9]	Metropolitan	1.21	100.0	0.000
Nara	Contraction	0.000	-25.1 [-36.3, -12.5]	Metropolitan	1.55	100.0	0.000
Wakayama	Contraction	0.000	-23.5 [-30.5, -15.6]	Non-metropolitan	1.67	100.0	0.000
Tottori	Contraction	0.000	-42.7 [-57.4, -26.4]	Non-metropolitan	0.84	100.0	0.000
Shimane	Contraction	0.000	-49.6 [-64.3, -31.0]	Non-metropolitan	0.72	100.0	0.000

Prefecture	Typology	Pr(increase)	Stock change median [95%] (%)	Metro group	Average investment / 2021 stock (%)	Sustaining share 2050 (%)	Pr(new > 0 in 2050)
Okayama	Contraction	0.000	-32.8 [-47.3, -15.3]	Non-metropolitan	1.25	100.0	0.001
Hiroshima	Contraction	0.000	-37.4 [-50.2, -22.6]	Non-metropolitan	1.02	100.0	0.000
Yamaguchi	Contraction	0.000	-27.4 [-35.3, -18.4]	Non-metropolitan	1.47	100.0	0.000
Tokushima	Contraction	0.000	-44.9 [-58.4, -28.4]	Non-metropolitan	0.71	100.0	0.000
Kagawa	Contraction	0.002	-32.0 [-48.4, -11.4]	Non-metropolitan	1.33	100.0	0.002
Ehime	Contraction	0.000	-29.2 [-39.1, -18.5]	Non-metropolitan	1.40	100.0	0.000
Kochi	Contraction	0.002	-34.3 [-48.8, -14.0]	Non-metropolitan	1.16	100.0	0.005
Fukuoka	Contraction	0.058	-7.4 [-15.9, 1.9]	Non-metropolitan	2.41	100.0	0.000
Saga	Contraction	0.003	-24.4 [-37.9, -8.4]	Non-metropolitan	1.62	100.0	0.003
Nagasaki	Contraction	0.000	-35.4 [-47.2, -21.4]	Non-metropolitan	1.11	100.0	0.000
Kumamoto	Contraction	0.001	-33.3 [-49.3, -14.0]	Non-metropolitan	1.22	100.0	0.001
Oita	Contraction	0.000	-26.2 [-37.8, -13.3]	Non-metropolitan	1.54	100.0	0.000
Miyazaki	Contraction	0.000	-36.0 [-52.4, -18.8]	Non-metropolitan	1.10	100.0	0.000
Kagoshima	Contraction	0.000	-32.9 [-48.8, -15.2]	Non-metropolitan	1.25	100.0	0.000
Okinawa	Contraction	0.042	-12.3 [-25.2, 1.8]	Non-metropolitan	2.22	100.0	0.001

Notes: Typology is based on the posterior probability of stock increase: expansion ≥ 0.80, contraction ≤ 0.20, and uncertain or broadly stable otherwise. Stock change is measured from observed 2020 to the 2050 baseline forecast. Investment indicators use the baseline income scenario and baseline productive-capacity-loss rates.

Table S9: Metropolitan and non-metropolitan summary

Sector	Group	N prefectures	Median stock change (%)	Median Pr(increase)	Median investment / 2021 stock (%)	Median sustaining share 2050 (%)
Educational facilities	Metropolitan	11	-30.8	0.000	1.31	100.0
Educational facilities	Non-metropolitan	36	-34.8	0.000	1.14	100.0
Roads	Metropolitan	11	0.0	0.505	1.54	100.0
Roads	Non-metropolitan	36	5.0	0.816	1.73	97.0
Sewerage	Metropolitan	11	-17.9	0.000	0.81	100.0
Sewerage	Non-metropolitan	36	-21.2	0.000	0.67	100.0
Water supply	Metropolitan	11	-3.2	0.150	1.31	100.0
Water supply	Non-metropolitan	36	-8.0	0.104	1.13	100.0

Notes: Summary statistics are medians of prefecture-level posterior medians within the metropolitan and non-metropolitan groups.

Table S10: Long-horizon forecast robustness

Panel A. Model comparison: 2050 stock index (2020 = 100)

Sector	M1	M2	M3
Roads	115.8	105.7 [102.7, 108.9]	107.8 [104.6, 111.5]
Water supply	105.0	97.1 [95.0, 99.1]	96.6 [94.2, 99.0]
Sewerage	90.2	87.6 [86.0, 89.3]	87.3 [85.2, 89.6]
Educational facilities	74.1	71.8 [68.4, 75.2]	72.5 [68.8, 76.1]

Panel B. Alternative estimation samples, education-age definitions, and priors

Sector	Specification	population_variable	2050 stock index	Average annual investment (trillion yen)
Roads	Estimation sample 1990-2020	Total population	109.7 [105.6, 114.3]	5.48 [5.03, 5.97]
Roads	Estimation sample 2000-2019	Total population	105.3 [102.3, 108.6]	4.90 [4.57, 5.26]
Roads	Estimation sample 2005-2020	Total population	125.2 [119.7, 132.0]	7.13 [6.53, 7.86]
Roads	Main estimation sample 2000-2020	Total population	107.8 [104.6, 111.5]	5.20 [4.85, 5.60]
Roads	Tighter regularizing priors on main 2000-2020 specification	Total population	107.8 [104.6, 111.4]	5.19 [4.84, 5.59]
Roads	Wider priors on main 2000-2020 specification	Total population	107.7 [104.5, 111.4]	5.19 [4.83, 5.59]
Water supply	Estimation sample 1990-2020	Total population	97.3 [93.9, 100.9]	0.77 [0.70, 0.84]
Water supply	Estimation sample 2000-2019	Total population	96.1 [93.8, 98.5]	0.72 [0.67, 0.77]
Water supply	Estimation sample 2005-2020	Total population	109.7 [105.7, 114.1]	1.03 [0.94, 1.13]
Water supply	Main estimation sample 2000-2020	Total population	96.6 [94.2, 99.0]	0.73 [0.68, 0.79]
Water supply	Tighter regularizing priors on main 2000-2020 specification	Total population	96.6 [94.2, 99.1]	0.73 [0.68, 0.79]
Water supply	Wider priors on main 2000-2020 specification	Total population	96.6 [94.2, 99.1]	0.73 [0.68, 0.79]
Sewerage	Estimation sample 1990-2020	Total population	82.1 [76.9, 87.4]	0.85 [0.71, 1.00]
Sewerage	Estimation sample 2000-2019	Total population	86.3 [84.3, 88.5]	0.83 [0.77, 0.90]
Sewerage	Estimation sample 2005-2020	Total population	87.6 [85.7, 89.6]	0.87 [0.81, 0.94]
Sewerage	Main estimation sample 2000-2020	Total population	87.3 [85.2, 89.6]	0.86 [0.79, 0.94]
Sewerage	Tighter regularizing priors on main 2000-2020 specification	Total population	87.3 [85.3, 89.7]	0.86 [0.80, 0.94]
Sewerage	Wider priors on main 2000-2020 specification	Total population	87.3 [85.2, 89.6]	0.86 [0.79, 0.94]
Educational facilities	Educational facilities: population aged 5-14	Ages 5-14	72.1 [68.5, 75.5]	0.71 [0.64, 0.78]
Educational facilities	Educational facilities: population aged 5-24	Ages 5-24	74.2 [70.6, 77.6]	0.76 [0.69, 0.83]
Educational facilities	Estimation sample 1990-2020	Ages 5-19	75.3 [71.9, 78.5]	0.77 [0.70, 0.84]
Educational facilities	Estimation sample 2000-2019	Ages 5-19	72.4 [68.6, 76.0]	0.72 [0.65, 0.80]

Sector	Specification	population_variable	2050 stock index	Average annual investment (trillion yen)
Educational facilities	Estimation sample 2005-2020	Ages 5-19	70.8 [66.6, 74.9]	0.69 [0.61, 0.78]
Educational facilities	Main estimation sample 2000-2020	Ages 5-19	72.5 [68.8, 76.1]	0.72 [0.65, 0.80]
Educational facilities	Tighter regularizing priors on main 2000-2020 specification	Ages 5-19	72.5 [68.9, 76.0]	0.72 [0.65, 0.80]
Educational facilities	Wider priors on main 2000-2020 specification	Ages 5-19	72.6 [69.1, 76.2]	0.73 [0.65, 0.80]

Notes: Panel A compares the 2050 national stock index across Models 1–3. Panel B reports Model 3 forecasts under alternative estimation windows, education-age definitions, and prior scales. Bayesian entries report posterior medians with 95% credible intervals in brackets.

Table S11: Historical-income-cap sensitivity

Sector	Effect of cap on 2050 stock	Effect of cap on average investment
Roads	-4.85 [-6.67, -3.10]	-10.79 [-14.69, -7.03]
Water supply	-2.60 [-4.20, -0.98]	-7.37 [-11.33, -3.01]
Sewerage	-0.03 [-1.37, 1.34]	-0.43 [-4.54, 3.99]
Educational facilities	8.70 [6.08, 11.63]	16.36 [11.37, 21.64]

Notes: Entries report percentage changes relative to the baseline, with 95% credible intervals in brackets. Each prefecture's future real per capita income is capped at its maximum observed value over 2000–2020. This is a mechanical stress test rather than an alternative probabilistic forecast.

Table S12: Effective productive-capacity-loss calibration and investment sensitivity

Panel A. Alternative calibration cases

Sector	Case	Rate (%)	Period	Statistic	Includes disaster restoration
Educational facilities	baseline_fixed	2.671	2000-2020	median	Yes
Educational facilities	median_2010_2019	2.912	2010-2019	median	Yes
Educational facilities	mean_2016_2020	3.074	2016-2020	mean	Yes
Educational facilities	mean_2015_2019	3.009	2015-2019	mean	Yes
Educational facilities	exclude_disaster_median_2000_2020	2.611	2000-2020	median	No
Roads	baseline_fixed	1.516	2000-2020	median	Yes
Roads	median_2010_2019	1.536	2010-2019	median	Yes
Roads	mean_2016_2020	1.615	2016-2020	mean	Yes
Roads	mean_2015_2019	1.592	2015-2019	mean	Yes
Roads	exclude_disaster_median_2000_2020	1.450	2000-2020	median	No
Sewerage	baseline_fixed	1.529	2000-2020	median	Yes

Sector	Case	Rate (%)	Period	Statistic	Includes disaster restoration
Sewerage	median_2010_2019	1.680	2010-2019	median	Yes
Sewerage	mean_2016_2020	1.752	2016-2020	mean	Yes
Sewerage	mean_2015_2019	1.725	2015-2019	mean	Yes
Sewerage	exclude_disaster_median_2000_2020	1.471	2000-2020	median	No
Water supply	baseline_fixed	1.424	2000-2020	median	Yes
Water supply	median_2010_2019	1.485	2010-2019	median	Yes
Water supply	mean_2016_2020	1.507	2016-2020	mean	Yes
Water supply	mean_2015_2019	1.498	2015-2019	mean	Yes
Water supply	exclude_disaster_median_2000_2020	1.385	2000-2020	median	No

Panel B. Bootstrap uncertainty in baseline rates

Sector	Mean (%)	Median (%)	Lower 95% (%)	Upper 95% (%)	Draws
Educational facilities	2.634	2.671	2.362	2.885	30000
Roads	1.521	1.516	1.512	1.551	30000
Sewerage	1.538	1.529	1.367	1.668	30000
Water supply	1.413	1.424	1.339	1.479	30000

Panel C. Investment outcomes under alternative rates

Sector	Case	Average annual total investment: median [95%] (trillion yen)	2050 total investment: median [95%] (trillion yen)	2050 sustaining share: median [95%] (%)
Roads	baseline_fixed	5.20 [4.85, 5.60]	5.24 [4.63, 5.97]	76.7 [72.4, 80.6]
Roads	median_2010_2019	5.26 [4.91, 5.66]	5.30 [4.69, 6.03]	76.9 [72.7, 80.8]
Roads	mean_2016_2020	5.49 [5.14, 5.90]	5.54 [4.92, 6.28]	77.9 [73.8, 81.7]
Roads	mean_2015_2019	5.42 [5.07, 5.83]	5.47 [4.86, 6.21]	77.6 [73.5, 81.4]
Roads	exclude_disaster_median_2000_2020	5.00 [4.66, 5.40]	5.04 [4.43, 5.76]	75.7 [71.4, 79.7]
Roads	bootstrap_median_uncertainty	5.22 [4.85, 5.62]	5.26 [4.64, 5.98]	76.7 [72.5, 80.6]
Water supply	baseline_fixed	0.73 [0.68, 0.79]	0.61 [0.53, 0.70]	88.0 [81.5, 94.5]
Water supply	median_2010_2019	0.77 [0.72, 0.82]	0.64 [0.56, 0.73]	88.6 [82.4, 94.8]
Water supply	mean_2016_2020	0.78 [0.73, 0.83]	0.65 [0.57, 0.74]	88.8 [82.7, 94.9]
Water supply	mean_2015_2019	0.77 [0.72, 0.83]	0.65 [0.57, 0.74]	88.7 [82.6, 94.8]
Water supply	exclude_disaster_median_2000_2020	0.71 [0.66, 0.76]	0.59 [0.51, 0.68]	87.6 [80.9, 94.3]
Water supply	bootstrap_median_uncertainty	0.73 [0.66, 0.80]	0.60 [0.51, 0.70]	87.9 [81.2, 94.4]

Sector	Case	Average annual total investment: median [95%] (trillion yen)	2050 total investment: median [95%] (trillion yen)	2050 sustaining share: median [95%] (%)
Sewerage	baseline_fixed	0.86 [0.79, 0.94]	0.65 [0.55, 0.77]	90.8 [87.4, 93.5]
Sewerage	median_2010_2019	0.98 [0.91, 1.06]	0.76 [0.65, 0.88]	92.1 [89.1, 94.5]
Sewerage	mean_2016_2020	1.04 [0.97, 1.11]	0.81 [0.70, 0.93]	92.6 [89.8, 94.8]
Sewerage	mean_2015_2019	1.02 [0.95, 1.09]	0.79 [0.69, 0.91]	92.4 [89.5, 94.7]
Sewerage	exclude_disaster_median_2000_2020	0.82 [0.75, 0.89]	0.61 [0.52, 0.72]	90.2 [86.6, 93.1]
Sewerage	bootstrap_median_uncertainty	0.87 [0.71, 1.02]	0.66 [0.50, 0.83]	90.9 [86.5, 93.9]
Educational facilities	baseline_fixed	0.72 [0.65, 0.80]	0.45 [0.35, 0.55]	96.1 [89.1, 100.0]
Educational facilities	median_2010_2019	0.83 [0.75, 0.90]	0.53 [0.42, 0.64]	96.6 [90.5, 100.0]
Educational facilities	mean_2016_2020	0.89 [0.81, 0.97]	0.58 [0.47, 0.70]	96.9 [91.3, 100.0]
Educational facilities	mean_2015_2019	0.87 [0.79, 0.95]	0.56 [0.45, 0.67]	96.8 [91.0, 100.0]
Educational facilities	exclude_disaster_median_2000_2020	0.70 [0.63, 0.77]	0.43 [0.34, 0.53]	95.9 [88.6, 100.0]
Educational facilities	bootstrap_median_uncertainty	0.71 [0.57, 0.85]	0.44 [0.31, 0.58]	96.0 [88.5, 100.0]

Notes: Rates are accounting-based calibration parameters. Investment outcomes use the same posterior stock paths but apply the indicated productive-capacity-loss calibration. Monetary values are trillion yen at 2015 prices.

Supplementary Figures

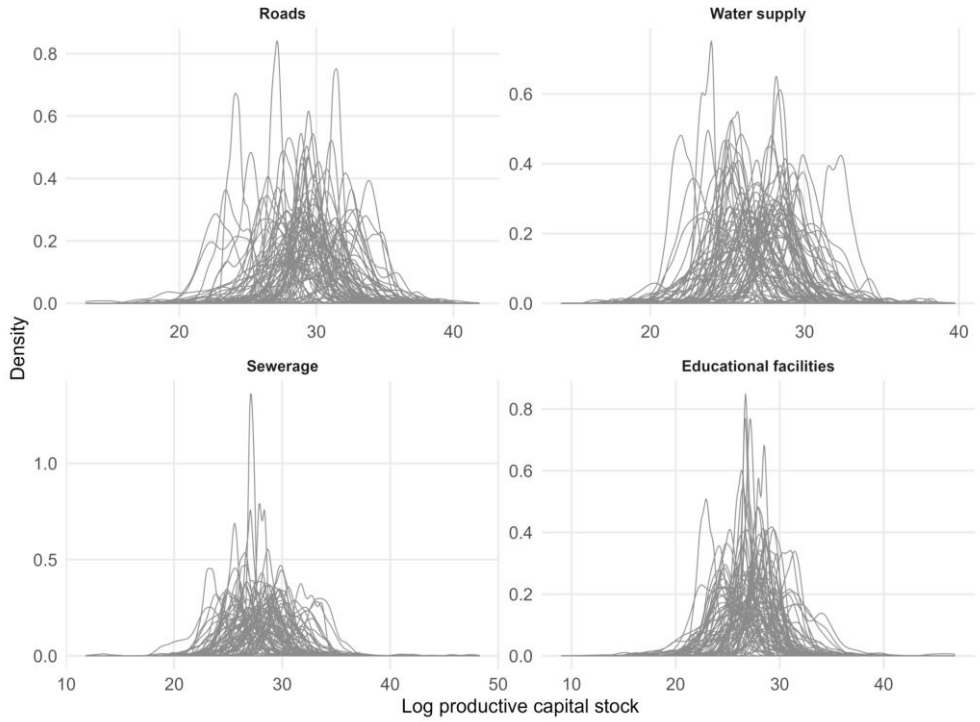


Figure S1: Prior predictive distributions for Model 3

Notes: Each line is a prior predictive density for log productive capital stock generated before conditioning on the observed outcome data. The figure assesses whether the regularizing priors place substantial probability on plausible outcome scales.

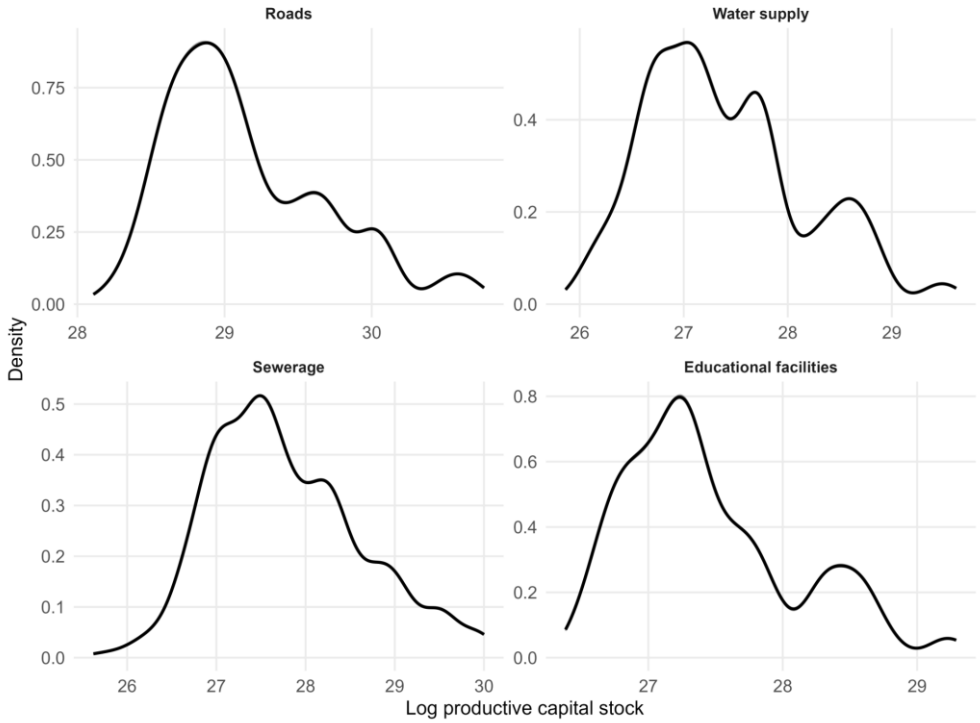


Figure S2: Posterior predictive distribution checks for Model 3

Notes: Black lines show observed distributions of log productive capital stock; grey lines show posterior predictive distributions from Model 3. The checks assess whether the fitted model reproduces the location, dispersion, and broad

shape of the observed sectoral distributions.

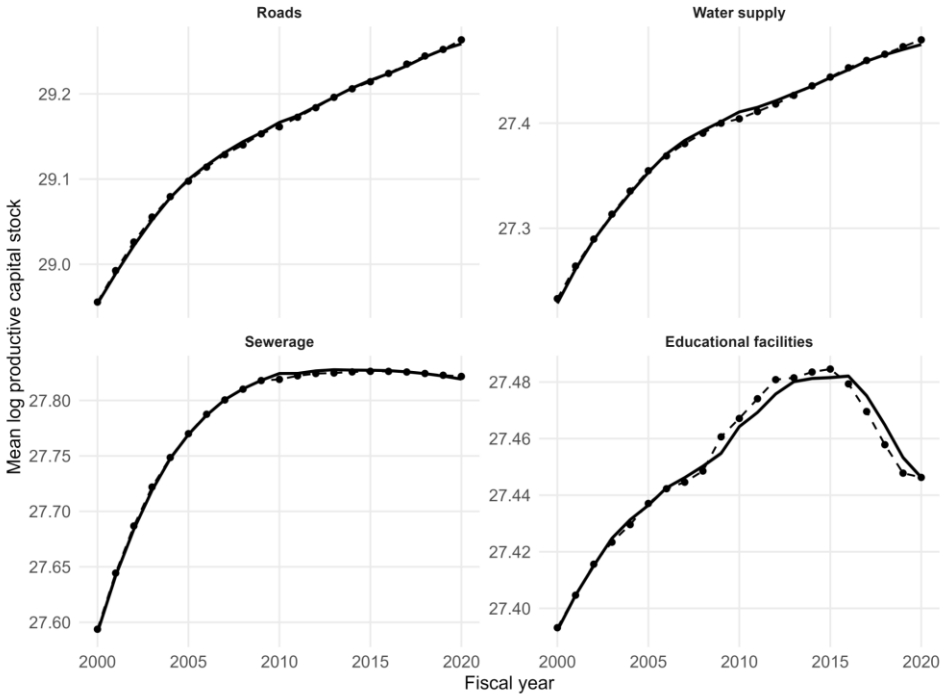


Figure S3: Trend posterior predictive checks for Model 3

Notes: The horizontal axis shows fiscal year and the vertical axis shows the prefecture mean of log productive capital stock. Dashed lines and points show observed annual means; solid lines show posterior expected annual means. Shaded bands, where visible, show 95% posterior credible intervals.

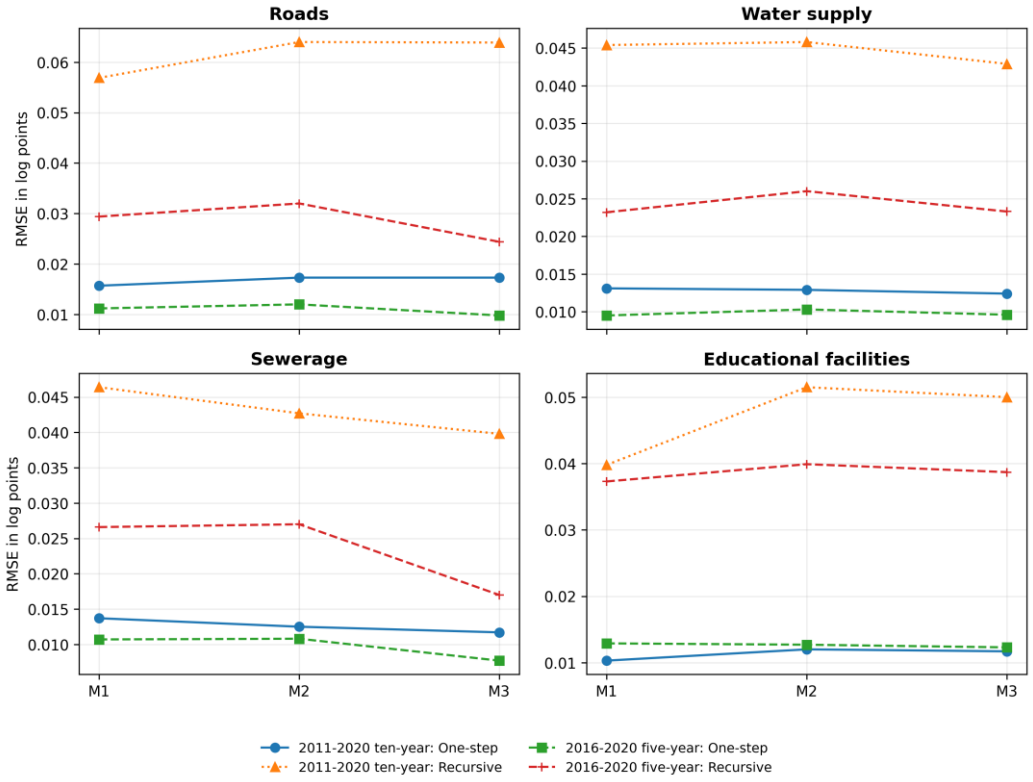


Figure S4: Temporally ordered holdout RMSE

Notes: The figure reports RMSE in log points for one-step-ahead and recursive forecasts over five-year and ten-year holdout periods. Lower values indicate better performance. M1 is the prefecture fixed-effects benchmark, M2 is the Bayesian random-intercept model, and M3 additionally allows prefecture-specific income coefficients.

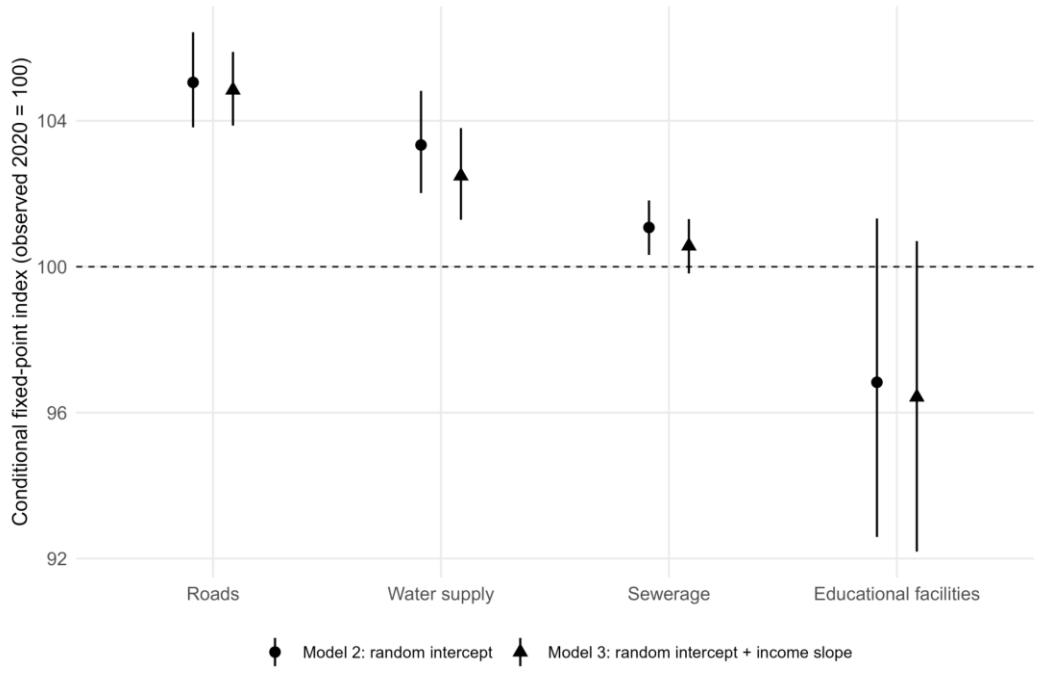


Figure S5: Conditional fixed points under socioeconomic covariates held at their 2020 values

Notes: Points report posterior medians and vertical bars report 95% credible intervals for national conditional fixed-point indices, normalized so that observed 2020 stock equals 100. Model 2 includes prefecture-specific random intercepts; Model 3 additionally allows prefecture-specific income coefficients. All posterior draws satisfy |phi| < 1. Fixed points are mathematical convergence values, not social optima, deficits, or policy targets.

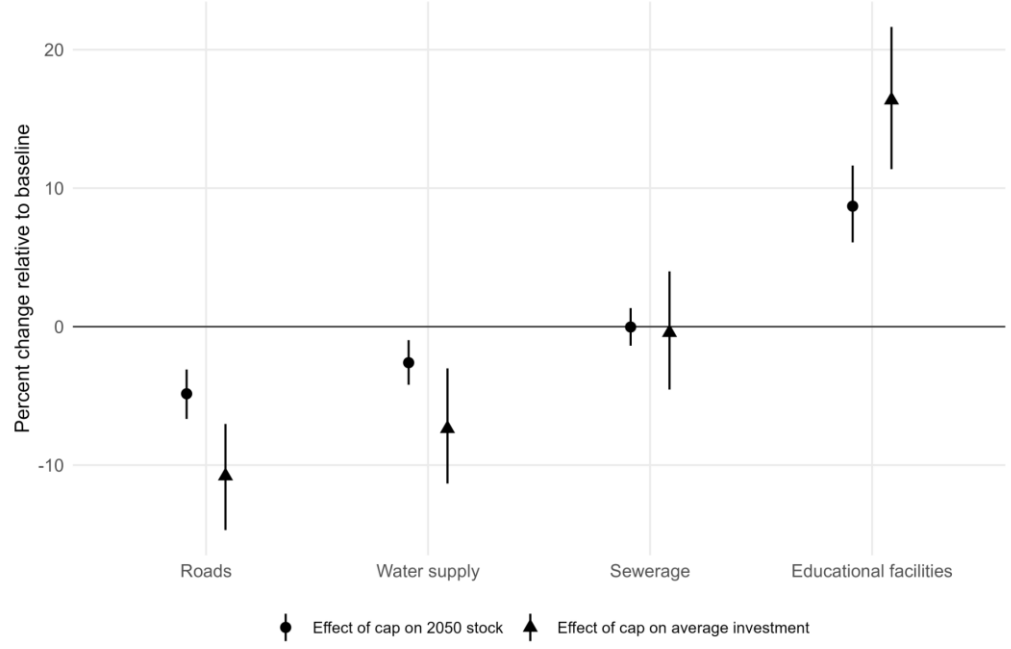


Figure S6: Sensitivity to capping future prefectural income at historically observed maximum

Notes: Points report posterior median percentage changes relative to the baseline and vertical bars report 95% credible intervals. Circles show the effect on the 2050 national model-implied stock and triangles show the effect on average annual gross investment over 2021–2050. The cap holds each prefecture's future real per capita income at no more than its maximum observed value over 2000–2020. This is a mechanical stress test, not an alternative probabilistic forecast.

Abstract (in Japanese)

要　約

本稿は、人口減少下における地域別インフラ投資を予測するための、ストック・フロー整合的な枠組みを構築する。道路、水道、下水道および教育施設を対象として、2000～2020 年度の日本の 47 都道府県データに部門別ベイズ階層動学モデルを適用する。公的な将来人口推計と複数の実質所得経路を用いて、事後分布に基づくインフラストック経路を 2050 年まで予測し、会計的に導いた生産能力減少率を用いて年間粗投資額へ変換する。この変換では、新規拡張投資と持続的資本投資を区分するとともに、残存する生産能力がモデルから導かれるストックを上回る場合には、能力退出を記録する。

採用した推定仕様の下では、全国の道路ストックは観測された 2020 年から 2050 年までに 7.8%増加する一方、水道、下水道および教育施設は、それぞれ 3.4%、12.7%および 27.5%減少する。4 部門合計の粗投資額は、2021 年の 9.12 兆円から 2050 年の 6.95 兆円へ減少するものの、2050 年の総額の約 80%を持続的資本投資が占める。道路の拡張という方向性は比較的頑健であるが、その規模は推定期間と所得経路に敏感である。水道の結果は推定仕様に依存する一方、下水道および教育施設の縮小はより安定している。残存する拡張投資は地理的に集中しているため、全国集計値だけでは、多くの都道府県で投資構成がほぼ全面的に持続的資本投資へ移行することが見えにくい。

これらの結果は、人口減少を一律の投資削減の根拠とすることが適切でないことを示す。長期的な計画では、新規拡張、持続的資本投資および能力退出を区別し、部門間・地域間で財政的・技術的資源を再配分する必要がある。日本は、人口減少と既存インフラの蓄積に直面する他の成熟・新興経済にとって、先行事例を提供する。本稿の推計値は条件付きの計画ベンチマークであり、厚生を最大化するストックや工学的必要量を示すものではない。

キーワード： インフラ、公共資本、人口減少、日本、ベイズ階層モデル

JEL コード： C11、C53、H54、R53