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Does Infrastructure Improve Human Well-being? Analysis of Japan's Subnational Human Development Index (1960–2020)

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Does Infrastructure Improve Human Well-being?
Analysis of Japan's Subnational Human Development Index (1960–2020)

Fumiaki Ishizuka*

Abstract

Infrastructure affects a wide range of human activities. This paper examines the impact of infrastructure on the level of human well-being by analyzing long-term panel data (1960–2020) on the newly constructed Human Development Index (HDI) for each prefecture in Japan. The analysis shows that infrastructure generally has a positive impact on HDI. The impact of total transport, water and sanitation, and education infrastructure on HDI is found to be significantly positive, with HDI increasing by 0.016 for every 1% increase in infrastructure stock. This positive impact is largely attributable to transport infrastructure, which contributes to higher productivity and economic growth through increased economic activity of people and firms and higher school enrollment through improved access to schools. However, the transport infrastructure has a negative impact on life expectancy, which may be attributed to the worsening of traffic accidents and air pollution in the 1960s and 1970s. The results of the above analysis contribute to clarifying the general relationship between infrastructure and human well-being. The results provide a more multifaceted evaluation of Japan's infrastructure, allowing insights into the increasing investment in infrastructure for emerging economies.

Keywords: Infrastructure, Public capital, Human Development Index, Japan, Transport, Water and sanitation, Education

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1. Introduction

Infrastructure affects a wide range of human social activities. Of these, perhaps the best known is the effect of infrastructure stock on productivity and economic growth, and the results of previous empirical studies have generally shown a positive effect on productivity (Bom and Ligthart 2014; Núñez-Serrano and Velázquez 2017). In addition, recent empirical studies using microdata have revealed that infrastructure has effects on various aspects of human life other than productivity, such as poverty, inequality, and employment (Foster et al. 2023). However, these studies have primarily focused on the effects on individual aspects, and the literature is limited in analyzing the effects across a wide range of human activities on a single scale.

The Human Development Index (HDI), introduced in 1990 by the United Nations Development Programme (UNDP), is the most widely used indicator of human well-being. The index consists of three components: income, education, and life. The UNDP publishes country-by-country figures in its annual Human Development Report. Although the HDI has been criticized for oversimplification (Klugman et al. 2011; Ravallion 2012), it continues to be the leading indicator in terms of providing a single comprehensive measure of the multiple dimensions of human activity.

The literature on the quantitative analysis of the impact of infrastructure on HDI remains limited, featuring cross-country analyses conducted at the national level (Acheampong et al. 2022; Maket, Kano, and Vas 2024; Sapkota 2014) and subnational level studies that often span only limited time periods (Kusharjanto and Kim 2011; Mohanty, Nayak, and Chatterjee 2016). These analyses are largely consistent in demonstrating a positive impact of infrastructure on overall HDI. However, when looking at infrastructure by sector, such as roads and water supply, the direction of its impact on HDI (the sign of the coefficient) differs across the literature.

This paper examines the impact of infrastructure on the level of human well-being by analyzing long-term panel data (1960–2020) on the newly constructed HDI for each prefecture in Japan. Specifically, I conducted a dynamic panel data analysis using HDI and its components as explained variables and infrastructure stocks in the three sectors of transport, water and sanitation, and education as explanatory variables. I then estimated the causal relationship between the two. In doing so, I used a difference GMM (Arellano-Bond Estimator) to address the endogenous nature of infrastructure (i.e., the possibility of reverse causality).

The analysis shows that infrastructure generally has a positive impact on HDI. The impact of total transport, water and sanitation, and education infrastructure on HDI is found to be significantly positive, with HDI increasing by 0.016 for every 1% increase in infrastructure stock. This positive impact is largely attributable to transport infrastructure, which contributes to higher productivity and economic growth through increased economic activity of people and firms and higher school enrollment through improved access to schools. However, the transport infrastructure shows a negative impact on life expectancy, which may be attributed to the worsening of traffic accidents and air pollution in the 1960s and 1970s.

The significance of this paper is, first, that it contributes to clarifying the general relationship between infrastructure and human well-being. As noted above, while there is growing evidence of the impact of infrastructure on several social dimensions other than productivity and economic growth (e.g., poverty, inequality, employment), studies analyzing the impact across a wide range of human activities on a single scale remain scarce. Visualizing the long-term relationship between infrastructure and the overall well-being of people from a broad perspective can provide a more multifaceted view of the diverse effects of infrastructure.

Second, it allows for a more multifaceted evaluation of Japan's infrastructure. There have been numerous studies on the impact of Japan's infrastructure on productivity (Ishizuka 2024). Apart from studies focusing on specific areas, such as the analysis of land prices based on the capitalization hypothesis, the literature analyzing the impact of infrastructure on social aspects other than productivity and economic growth has remained limited. This paper is the first analysis to identify the impact of infrastructure on such social dimensions in Japan using a measure of human well-being.

Third, it also provides insights into infrastructure investment in growing emerging economies. The analysis is based on long-term data for the period from 1960 to 2020: Japan's real GDP in 1960 was about one-fifth that of Japan in 2020, and below that of many countries in the world today. Since then, the country has experienced different economic phases, a period of rapid economic growth and the subsequent “lost 30 years,” while continuing to invest in a certain amount of infrastructure. During this period, the country has also experienced a declining birth rate, an aging population, and, since the 2000s, a declining population. In recent years, it has faced the problem of aging existing infrastructure and its replacement investment. Visualizing the long-term impact of the infrastructure stock for this series of periods could also be a reference for countries other than Japan.

Fourth, I provide the first dataset of HDI for each prefecture in Japan. There has been discussion in Japan about the need to focus on and visualize the level of human well-being rather than solely on productivity or economic growth. In addition, recent international discussions on well-being have highlighted the need for analysis at the subnational level—rather than at the national level—in order to focus on differences and disparities among regions and groups within a given country

(Smits and Permanyer 2019; Sherman et al. 2023)[1]. The construction of this new dataset is in line with this trend and is expected to stimulate future research on well-being in Japan.

This paper is organized as follows. The next section explains the model specifications and estimation methods employed in this analysis. Section 3 describes the data sources and processing methods, including HDI and infrastructure stock. Section 4 presents the estimation results, including robustness checks, and their interpretation. Section 5 concludes with a summary of the main findings and a discussion of areas for future research. The Appendix details the methods and results of the robustness checks.

2. Methodology

2.1 Model specification

The model employed in this analysis is as follows:

$$y_{it} = \beta_1 y_{i\,t-1} + \beta_2 x_{it} + \beta_3 Z_{it} + \varepsilon_{it} \qquad (1)$$

Of the above, y_{it} is the HDI or its three components (income index, education index, and life index) in prefecture i and year t, $y_{i\,t-1}$ is its first lag, x_{it} is the infrastructure stock, Z_{it} is a vector of control variables, ε_{it} is the error term, and β_k are the parameters to be estimated.

Four types of infrastructure stock were used: transport, water and sanitation, and education, as well as the sum of the three sectors. Since a high correlation was observed between the variables in each of the above three sectors, separate models were created, one for each variable, rather than including all three variables in a single model at the same time. In the telecommunications, electricity, and health sectors, the private sector is the main business provider in Japan, and it is difficult to obtain comparable infrastructure stock data.

In addition, in order to control for the impact of factors other than infrastructure stock on the HDI and its components, the following control variables were included based on the literature mentioned above: population and urbanization rate (economies of agglomeration), percentage of elderly persons aged 65 years or older in the total population (demography), percentage of primary and secondary industry workers in the total number of employed persons (industrial structure), and per capita local taxes (fiscal size of local governments).

In addition, three time period dummies were included to capture structural changes in each period: FY1960-80, FY1981-2000, and FY2001-2020. The year dummies were not used because many were insignificant, including the years in which the effects of the oil shocks and the Lehman

[1] The subnational HDI developed by Smits and Pearmanyer (2019) includes data on Japan, although this data is at the level of regional blocks consisting of multiple prefectures and is limited to a short term after 2000.

Brothers collapse were likely to have been felt.

2.2 Estimation method

To address the issue of endogeneity (the possibility of reverse causality) that is often raised in empirical analyses of infrastructure stocks, I estimate by difference GMM using the Arellano-Bond estimator (Arellano and Bond 1991). While removing fixed effects by taking the difference, endogeneity is eliminated by using instrumental variables. For the results of each analysis, I confirm by testing that no second-order serial correlation remains in the error term and that the instrumental variables employed are not correlated with the error term.

In addition to the above control variables, the lags of the explained variable and infrastructure stock were used as the instrumental variables, ranging from the 5th to the 30th order. Regarding the range of lags, lags from the first to the fourth order, which are most likely to be affected by endogeneity, were first excluded, because it takes a certain amount of time for the infrastructure stock effect to manifest itself. In addition, given that the longest service life of the infrastructure in question is 60 years (i.e., reinforced concrete bridges and water treatment plants), half of this time, i.e., 30 years, was set as the upper limit.

Note that in some cases in the literature, system GMMs have been used (Arellano and Bover 1995; Blundell and Bond 1998), which use level equations in addition to difference equations, but this approach was not used in this paper. The system GMM must satisfy the additional assumption that the difference of the instrumental variables is uncorrelated with the fixed effects. The instrumental variables used in this analysis include the lags of the HDI and past infrastructure stocks, and an example of the difference is the flow of past infrastructure investment. Since infrastructure investment flows may have some correlation with the economic and social nature specific to each prefecture, which are fixed effects, this analysis would not be able to satisfy the additional assumption above.

In addition, unit root and cointegration tests were conducted to rule out the possibility of spurious regressions and to confirm that cointegration relationships were established among the variables. For standard errors, I used clustered standard errors, which are robust to heteroskedasticity and serial correlation within each prefecture.

3. Data

3.1 General description

I constructed panel data for 47 prefectures consisting of HDI, infrastructure stock, and control variables. The time period was set to FY1960–2020 (FY1975–2020 for Okinawa only), when infrastructure stock statistics were available. Descriptive statistics are shown in Table 1. The data source and processing methods for each variable are presented in the following sections.

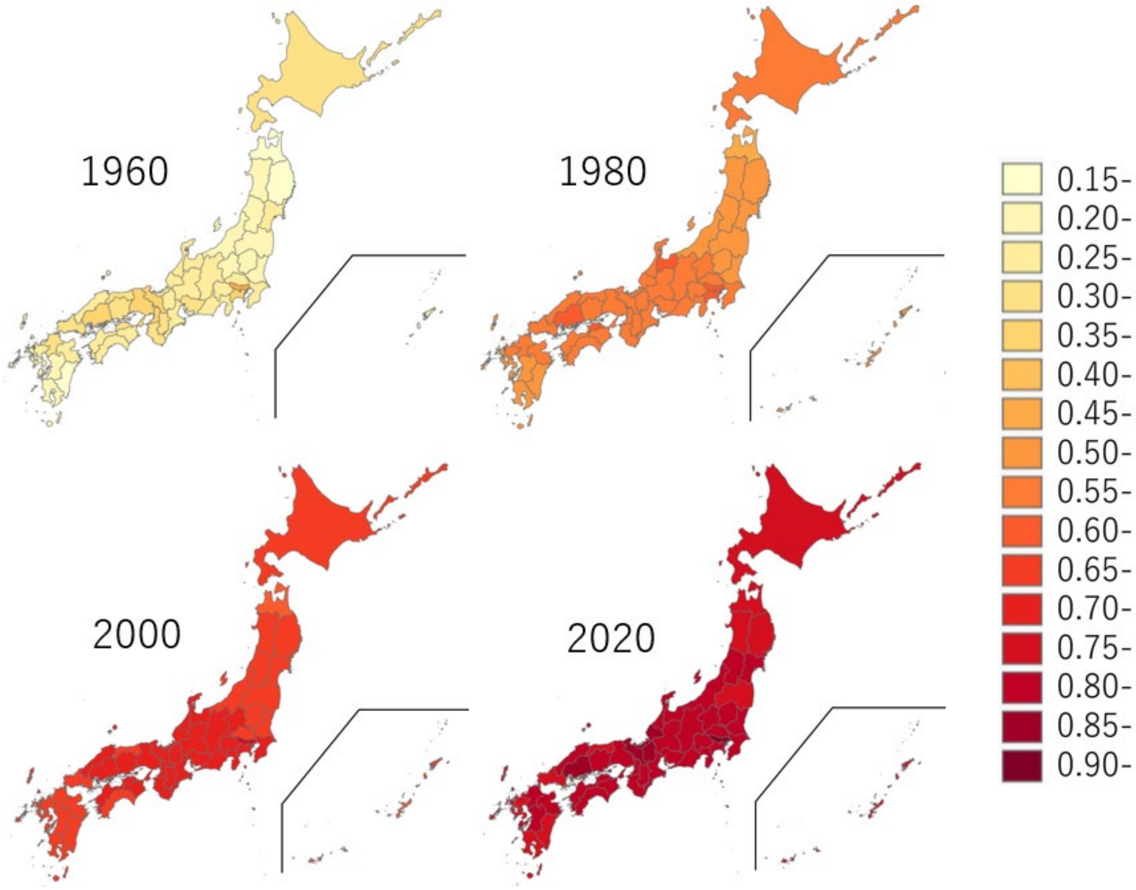
Table 1: Descriptive Statistics

	Observation	Mean	Standard deviation	Minimum	Maximum
Human Development Index (HDI)	2,852	0.65	0.15	0.19	0.91
Income index	2,852	0.71	0.13	0.27	1.00
Education index	2,852	0.65	0.17	0.07	0.96
Life index	2,852	0.60	0.16	0.20	0.85
Transport infrastructure per capita (ln)	2,852	13.94	0.87	11.82	15.57
Water and sanitation infrastructure per capita (ln)	2,852	12.64	1.30	8.98	14.26
Education infrastructure per capita (ln)	2,852	12.53	0.78	10.39	13.74
Total infrastructure per capita (ln)	2,852	14.39	0.90	12.18	15.91
Population (ln)	2,852	14.45	0.72	13.22	16.46
Elderly rate (%)	2,852	15.76	7.86	3.80	37.27
Urbanization rate (%)	2,852	46.40	19.12	15.29	98.55
Employed in primary industry (%)	2,852	14.45	12.15	0.37	60.37
Employed in secondary industry (%)	2,852	29.04	6.86	11.65	48.55
Local tax per person (ln)	2,852	11.85	0.72	9.46	13.22

3.2 HDI and its components

The HDI of each prefecture in Japan is constructed by calculating the geometric mean of three indices: income, education, and life. This calculation is performed using the same methodology as the UNDP HDI described in the Technical Note accompanying the Human Development Report. The index value basically shows an increasing trend during the period under study, but the rate of increase has become slower over the years. In addition, prefectures belonging to metropolitan areas such as Tokyo show relatively high values compared with rural areas throughout the period (Figure 1).

Figure 1: Trends in HDI in Japan by prefecture



The income index, one of the three components used to construct the HDI, is per capita prefectural income. The data source is the Prefectural Accounts [Kenmin Keizai Keisan] of the Cabinet Office of Japan[2]. The population data is from the National Census and Population Estimates of the Ministry of Internal Affairs and Communications of Japan. Since the data span the period of different SNA systems, the rate of change during the period of each SNA was calculated, and the data for all fiscal years were retroactively linked. To match the base year of the infrastructure stock, the data were converted to 2015 prices using the GDP deflator. In addition, I used arbitrary maximum (6,000,000 JPY) and minimum (100,000 JPY) values and indexed them to fall between 0 and 1.

The education index is the average enrollment rate in upper secondary and tertiary education. The UNDP HDI uses the number of years of schooling as the education index. Since the same data is not available in Japan, it is substituted by the average enrollment rate in upper secondary and tertiary education. Specifically, I adopted the sum of the "Rate of junior high school graduates going on to high school, etc. (excluding correspondence courses) (%)" and the "Rate of high school graduates (excluding correspondence courses) going on to university, etc. (excluding

2 https://www.esri.cao.go.jp/jp/sna/sonota/kenmin/kenmin_top.html

correspondence courses) (%)" from the Basic School Survey [Gakkou Kihon Chousa] of the Ministry of Education, Culture, Sports, Science and Technology of Japan[3]. The scope did not extend to elementary and junior high schools, as these institutions are part of the compulsory education system. Also, the rate of university graduates going on to graduate school was not added because such prefectural data did not exist. Arbitrary maximum (170%) and minimum (50%) values were used to index the rate to fall between 0 and 1.

The life expectancy index is the average life expectancy. The source of the data is the Life Tables by Prefecture [Todoufuken betsu Seimei Hyo] of the Ministry of Health, Labor and Welfare of Japan[4]. Since this data is only available every five years, I performed linear interpolation after confirming that there was a consistent upward trend over the target period. We used the maximum (90 years old) and minimum (60 years old) values to create an index ranging from 0 to 1.

3.3 Infrastructure Stock

The source of the infrastructure stock is the database attached to the Measuring Infrastructure in Japan 2023, a report on infrastructure stock published by the Cabinet Office of Japan[5]. The database covers infrastructure under the jurisdiction of the public sector and is expressed in monetary units. The values of three types of stock are published: 1) gross capital stock (value based on the acquisition price or investment amount), 2) productive capital stock (remaining capacity after deducting the decrease in efficiency due to the passage of years of use), and 3) net capital stock (remaining value after deducting the depreciation due to the passage of years of use). In this analysis, I use 2) productive capital stock, focusing on the amount of capacity of infrastructure stock to produce its services, to measure its impact on HDI and its components.

The above database includes infrastructure stock in 19 sectors. Of the 19 sectors, the three sectors of "Road," "Port" and "Aviation" were combined as Transport, the two sectors of "Water Supply" and "Sewerage" were combined as Water and Sanitation, and the two sectors of "Educational Facilities (School Facilities, Academic Facilities)" and "Educational Facilities (Social Education Facilities, Social Sports Facilities, Cultural Facilities)" were aggregated as Education. The per capita values were calculated for these three sectors (transport, water and sanitation, and education) along with their combined totals and then converted to logarithmic values. Note that "Railroad" is not included in the transport grouping because data is not available by prefecture.

3.4 Control Variables

The source of data on the population, urbanization rate, and elderly population rate is the Population Census and Population Estimates of the Ministry of Internal Affairs and

3 https://www.mext.go.jp/b_menu/toukei/chousa01/kihon/1267995.htm
4 https://www.mhlw.go.jp/toukei/saikin/hw/seimei/list54-57-02.html
5 https://www5.cao.go.jp/keizai2/ioj/result/ioj_data.html

Communications of Japan[6]. The urbanization rate was calculated by dividing the "Population of Densely Inhabited Districts" by the total population. Since data on the population of densely inhabited districts are only available every five years, I performed linear interpolation after checking the direction of the trend in each period. The elderly ratio was calculated by dividing the population aged 65 and over by the total population. Data for 1961–64 and 1966–69 were not available, so values for 1960 and 1965, and 1965 and 1970 were used, respectively, to perform linear interpolation after checking the direction of the trend during each period.

The source of the primary and secondary industry employment rate is also the census mentioned above. Primary industries include agriculture, forestry, and fishing. Secondary industries are manufacturing, construction, and mining. Since data on workers by industry are available only every five years, the data for each year were linearly interpolated after checking the direction of the trend during each period.

The source of the per capita local tax amounts is the Annual Report of Local Finance Statistics [Chihou Zaisei toukei Nenpou] of the Ministry of Internal Affairs and Communications of Japan[7]. For each prefectural category, the local tax amounts of both the prefectural government and the ward/municipal government were summed. The data for 1961–64 and 1966–69 was linearly interpolated using the values for 1960 and 1965, and 1965 and 1970, respectively, after confirming that there was a consistent upward trend over the target period. GDP deflators were used to convert the values to 2015 prices, and then per capita values were calculated.

4. Results

4.1 Estimation results

The results when HDI is taken as the explained variable are presented in Columns (1) to (4) in Table 2, where the total stock of infrastructure in the three sectors shows a significantly positive effect on HDI. Looking at the impact of each sector's infrastructure, transport infrastructure shows a significantly positive effect on HDI, while water and sanitation and education infrastructure do not yield significant results. As for the control variables, population, local taxes per capita, and 1981–2000 dummies all show significant results in all models. The sign of the coefficient for population was negative, while that for local taxes was positive. The 1981–2000 dummy showed a slightly negative impact compared to the base period 1960–1980. Control variables that showed significant results in some parts of the model include the elderly population rate, the urbanization rate, and the ratio of primary industry workers, but the magnitude of the coefficients for each is very small.

The results when each component of the HDI is taken as the explained variable are also shown in

[6] https://www.stat.go.jp/data/kokusei/2020/kekka.html

[7] https://www.soumu.go.jp/iken/zaisei/toukei.html

Columns (5) to (16) in Table 2. The models of Columns (5) to (12), in which the income and education indices are taken as explained variables, require certain reservations on the consistency of the models, as the AR (2) test results confirm the possibility of remaining second-order serial correlation in the error terms. Based on this assumption, the sum of the three sector infrastructures had a positive impact on the income and education indices. Transport infrastructure had a positive impact on the income and education indices, while it had a significantly negative impact on the life index. No significant results were obtained for water and sanitation or education infrastructures.

Table 2: Analysis results (all periods, productive capital stock)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Dependant variable	HDI	HDI	HDI	HDI	Income index	Income index	Income index	Income index	Education index	Education index	Education index	Education index	Life index	Life index	Life index	Life index
Ln total infrastructure	0.016***				0.019**				0.030*				-0.003			
(productive capital stock per person)	(0.006)				(0.009)				(0.017)				(0.003)			
Ln transport infrastructure		0.024***				0.029**				0.044***				-0.005**		
(productive capital stock per person)		(0.007)				(0.012)				(0.015)				(0.002)		
Ln water and sanitation infrastructure			0.000				0.002				-0.001				-0.000	
(productive capital stock per person)			(0.005)				(0.005)				(0.012)				(0.002)	
Ln education infrastructure				0.004				0.004				0.007				0.002
(productive capital stock per person)				(0.005)				(0.007)				(0.017)				(0.002)
L. dependant variable	0.888***	0.868***	0.928***	0.897***	0.793***	0.771***	0.805***	0.799***	0.941***	0.932***	0.951***	0.943***	0.992***	1.001***	0.975***	0.965***
	(0.025)	(0.028)	(0.026)	(0.022)	(0.029)	(0.033)	(0.025)	(0.028)	(0.034)	(0.033)	(0.030)	(0.031)	(0.027)	(0.022)	(0.029)	(0.022)
Ln population	-0.069***	-0.068***	-0.052**	-0.059***	-0.041*	-0.039*	-0.024	-0.028	-0.188***	-0.180***	-0.143**	-0.166***	-0.001	-0.002	-0.001	-0.002
	(0.020)	(0.019)	(0.024)	(0.015)	(0.024)	(0.021)	(0.024)	(0.025)	(0.067)	(0.060)	(0.069)	(0.061)	(0.004)	(0.004)	(0.003)	(0.003)
Elderly rate (%)	-0.001	-0.001**	-0.000	-0.000	-0.001***	-0.002***	-0.001***	-0.001***	-0.001	-0.001	0.000	0.000	-0.000	-0.000*	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Urbanization rate (%)	0.001*	0.001*	0.001	0.001*	-0.000	-0.000	-0.001	-0.000	0.003**	0.003**	0.003**	0.003***	-0.000	0.000	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Employed in primary industry (%)	0.002*	0.001*	0.001	0.001	0.001**	0.002**	0.001	0.001**	0.005*	0.005*	0.003	0.004	-0.000*	-0.000*	-0.000*	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.003)	(0.003)	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Employed in secondary industry (%)	0.001	0.000	0.000	0.000	-0.001	-0.001	-0.001*	-0.001	0.002	0.002	0.001	0.002	-0.000	-0.000	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Ln local tax amount per person	0.020***	0.020***	0.021***	0.023***	0.045***	0.045***	0.048***	0.046***	0.032***	0.029***	0.040***	0.038***	0.000	0.000	-0.000	0.000
	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.005)	(0.004)	(0.008)	(0.008)	(0.007)	(0.007)	(0.001)	(0.001)	(0.001)	(0.001)
Period dummy 1981-2000	-0.005***	-0.005***	-0.003***	-0.004***	-0.004***	-0.004***	-0.002*	-0.002	-0.011***	-0.011***	-0.008***	-0.009***	-0.002***	-0.002***	-0.002***	-0.001***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Period dummy 2001-2020	-0.000	-0.002	-0.001	0.001	-0.011***	-0.012***	-0.011***	-0.008***	-0.005	-0.007	-0.004	-0.001	-0.002	-0.002	-0.004	-0.002
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.008)	(0.009)	(0.006)	(0.008)	(0.003)	(0.003)	(0.003)	(0.003)
Observations	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758
AR(2) test p-value	0.197	0.108	0.115	0.246	0.014	0.017	0.015	0.012	0.007	0.006	0.008	0.012	0.753	0.887	0.682	0.630
Hansen test p-value	0.561	0.537	0.541	0.532	0.535	0.533	0.539	0.545	0.537	0.526	0.523	0.533	0.553	0.571	0.603	0.529

Notes: Clustered and heteroscedasticity robust standard errors are reported in parentheses. Stars indicate statistical significance: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

4.2 Robustness check

As a robustness check, I conducted two estimations: 1) using gross capital stock data instead of productive capital stock, and 2) splitting the sample into subsamples for three different time periods: 1960–1980, 1981–2000, and 2001–2020. In each case, I used the same model presented in Section 2.1 above. The details of the results are described in the Appendix.

The results of 1), both in terms of the reliability of each model based on the results of the AR (2) and Hansen tests, and in terms of the signs of the parameters of interest, show a similar trend to the results of the above analysis using the productive capital stock (Table A1), supporting the robustness of the analysis results presented in the previous section.

The results of 2) failed to meet the criteria of the AR (2) or Hansen test in many models (Tables A2-4). One possible reason for this is that the length of the time series data was too short to allow for lags of sufficient depth as instrumental variables. Among the few reliable models, the impact of transport infrastructure on the life index shows that the sign of the coefficient is significantly negative for the period 1960–1980, while it is positive, though not significant, for the period 2001–2020.

In the empirical analysis of infrastructure, to account for the network or spillover effects of public capital (especially highways and railways), there are cases where a) the infrastructure stock of neighboring areas is added as a separate variable, or b) the analysis is conducted on a regional block basis covering several prefectures. Since highways are included in the transport infrastructure in this analysis, both a) and b) above were attempted, but neither produced reliable results. Note that the road stock data used in this study is the aggregate value of all types of roads and cannot be divided between highways and other roads.

4.3 Discussion

The following three points emerge from the above results. First, infrastructure generally has a positive impact on the HDI: the impact of the total of the three sectors of infrastructure is significantly positive on the HDI, with each 1% increase in infrastructure stock increasing the HDI by 0.016. The effect on the HDI components is significantly positive for the income and education indices, although it should be noted that there is still a second-order serial correlation in the error term, so I can infer a positive effect on the HDI through an increase in these two indices. This finding of a generally positive impact of infrastructure on the HDI is consistent with the general view expressed in the previous literature analyzing the impact of infrastructure on the HDI.

Second, the above-mentioned positive impact of the infrastructure on the HDI is largely due to the impact of transport infrastructure at the sectoral level. The impact of the transport infrastructure stock on the HDI is significantly positive, and the magnitude of the impact is greater than that of the three sectors combined (each 1% increase in the transport infrastructure stock increases the HDI by 0.024). The effect on the HDI components is significantly positive for the income and education indices, although the second-order serial correlation in the error term remains, suggesting a positive effect on the HDI through increases in these two indices. As for the specific paths of the effect, the improvement of transport infrastructure contributed to the increase in productivity and economic growth by stimulating the economic activities of people and firms, and the improvement of access to schools—especially roads, among the transport infrastructure—contributed to the increase in the rate of students going to school. On the other hand, the absence of significant results for the education infrastructure may be attributable to the inclusion of infrastructure stock for compulsory education (elementary and junior high schools), while the HDI education indicator uses the rate of progression to high school and university. Furthermore, the absence of significant findings in the water and sanitation infrastructure may be attributed to Japan's attainment of a certain level of average life expectancy as early as the 1960s, which is more than 60 years old.

Third, however, transport infrastructure may also have a negative impact on the HDI, with a relatively small but significant negative impact on the life index among the components of the HDI. The results of specific period sample analysis indicate the significantly negative sign of the same coefficient for FY1960–1980, and positive sign for FY2001-2020 although not significant. In general, the pathways through which transport infrastructure may negatively affect health and life expectancy are generally considered to be the presence of traffic accidents and air pollution, as pointed out in the empirical literature on data from OECD countries (Grafenstein and Gao 2021). This mechanism may also be applicable to the case of Japan, though this requires further validation through additional research. Japan experienced a significant increase in the number of traffic accidents and fatalities during 1960s and 1970s, known as the “traffic wars.” This period was followed by a deterioration in air quality. Over the subsequent decades, the country implemented stricter traffic and environmental regulations, which led to improvements in these areas.

5. Conclusion

This paper examined the impact of infrastructure on the degree of human social well-being (well-being) through the analysis of newly constructed long-term panel data (1960–2020) on HDI by prefecture in Japan. Specifically, I conducted a dynamic panel data analysis using HDI and its components as explained variables, and infrastructure stocks in the three sectors of transport, water and sanitation, and education as explanatory variables. This suggested a causal relationship between the explained and explanatory variables. In doing so, the difference GMM (Arellano-

Bond Estimator) was used to address the endogeneity or the possibility of reverse causality.

The analysis shows that infrastructure generally has a positive impact on HDI. The impact of total transport, water and sanitation, and education infrastructure on HDI is found to be significantly positive, with HDI increasing by 0.016 for every 1% increase in infrastructure stock. This positive impact is largely attributable to transport infrastructure, which contributes to higher productivity and economic growth through increased economic activity of people and firms, and higher school enrollment through improved access to schools. However, the transport infrastructure shows a negative impact on life expectancy, which may be attributed to the worsening of traffic accidents and air pollution in the 1960s and 1970s.

The first direction for future research is to refine the analysis for each infrastructure sector. As this analysis has shown, even if infrastructure in general has a positive impact on HDI, the impact of each infrastructure sector is not uniform. Even within the same infrastructure sector, there are cases where not only positive but also negative paths exist, as in the case of the above-mentioned transport infrastructure. Further improvement of the model and collection of additional data (further back in the time series, and covering sectors other than transport, water and sanitation, and education) are possible directions for refinement.

The second is to verify the impact of infrastructure using more diverse indicators. The three components of the HDI are income, education, and life (life expectancy), but there are many other possible indicators of human well-being (e.g., safety, environment, solidarity, dignity). As the construction of such indicators progresses, it will also become necessary to examine the impact of infrastructure from a more multifaceted perspective.

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Appendix: Analysis Results for Gross Capital Stock and Period Samples

Table A1 to A4 presents 1) the results of the analysis when the infrastructure stock data are changed from productive capital to gross capital, and 2) the results of the analysis of the subsamples for three different periods, 1960–1980, 1981–2000, and 2001–2020. The models used in these analyses are the same as those used in the analysis of the full-period sample with productive capital stock.

1) The results of the analysis using the gross capital stock in Table A1 are similar to the results of the analysis using the productive capital stock in the text (Table 2), both in terms of the reliability of each model based on the results of the AR (2) and Hansen tests, and in terms of the signs of the parameters of interest.

2) The results of the analysis of the subsamples for three different periods are reliable only for the four models that took the life index as the explained variable for the period 1960–1980 ((13)-(16) in Table A2). The other models failed to meet the criteria for the AR (2) or Hansen tests. One possible reason for this is that the length of the time series data was too short to allow for lags of sufficient depth as instrumental variables. The details of the results of the reliable models mentioned above are presented below:

- Infrastructure for the three sectors combined has a significant negative impact on the life index in the 1960–1980 subsample ((13) in Table A2). This is likely due to the significant impact of transport and education infrastructure, as discussed below.
- Transport infrastructure had a significantly negative effect on the life index in the 1960–1980 subsample ((14) in Table A2). On the other hand, the sign of the coefficient changed to positive in the subsample for 2001–2020, although the significance of the coefficient and the AR (2) test did not meet the criterion ((14) in Table A4). Traffic accidents and air pollution are generally pointed out as pathways through which transport infrastructure negatively affects life expectancy. In Japan, the number of traffic accidents and pervasiveness of air pollution were severe in the 1960s and 1970s, but there has been an improvement in these events since then due to stricter traffic and environmental regulations. The change in the signs of the coefficients above may reflect these changes in social conditions.
- Education infrastructure also had a significant negative effect on the life index in the 1960–1980 subsample (Table A2, (16)). It is generally believed that educational infrastructure has a positive effect on life expectancy in the long run through higher living standards. The reasons for the negative coefficient in this period could be that it takes a long time for the above path to materialize, and the positive effect may have been delayed by the limited time period of 20 years in this sample, or that the investment in school facilities in this period may have crowded out investment in other areas that directly affect health.

Table A1: Analysis results (all periods, gross capital stock)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Dependant variable	HDI	HDI	HDI	HDI	Income index	Income index	Income index	Income index	Education index	Education index	Education index	Education index	Life index	Life index	Life index	Life index
Ln total infrastructure	0.016**				0.019**				0.028				-0.003			
(gross capital stock per person)	(0.007)				(0.009)				(0.018)				(0.003)			
Ln transport infrastructure		0.022***				0.026**				0.042**				-0.006**		
(gross capital stock per person)		(0.007)				(0.011)				(0.017)				(0.003)		
Ln water and sanitation infrastructure			-0.000				0.003				-0.002				-0.000	
(gross capital stock per person)			(0.005)				(0.005)				(0.012)				(0.002)	
Ln education infrastructure				0.004				0.004				0.006				0.001
(gross capital stock per person)				(0.006)				(0.007)				(0.019)				(0.003)
L. dependant variable	0.894***	0.883***	0.927***	0.899***	0.793***	0.771***	0.805***	0.799***	0.946***	0.938***	0.951***	0.944***	0.992***	1.001***	0.978***	0.965***
	(0.024)	(0.025)	(0.026)	(0.022)	(0.029)	(0.033)	(0.025)	(0.028)	(0.034)	(0.033)	(0.030)	(0.031)	(0.027)	(0.022)	(0.030)	(0.025)
Ln population	-0.069***	-0.065***	-0.051**	-0.059***	-0.040*	-0.036*	-0.024	-0.029	-0.184***	-0.175***	-0.141**	-0.167**	-0.001	-0.002	-0.001	-0.002
	(0.019)	(0.013)	(0.025)	(0.016)	(0.024)	(0.022)	(0.025)	(0.026)	(0.067)	(0.058)	(0.069)	(0.066)	(0.004)	(0.004)	(0.003)	(0.003)
Elderly rate (%)	-0.001*	-0.001***	-0.000	-0.000	-0.002***	-0.002***	-0.001***	-0.001***	-0.001	-0.001	0.000	0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Urbanization rate (%)	0.001*	0.001*	0.001	0.001*	-0.000	-0.000	-0.001	-0.000	0.003**	0.003**	0.003**	0.003***	-0.000	-0.000	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Employed in primary industry (%)	0.001*	0.002*	0.001	0.001	0.001**	0.001**	0.001	0.001**	0.005*	0.005*	0.003	0.004	-0.000*	-0.000*	-0.000*	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.003)	(0.003)	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Employed in secondary industry (%)	0.001	0.000	0.000	0.000	-0.001	-0.001	-0.001*	-0.001	0.002	0.002	0.001	0.002	-0.000	-0.000	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Ln local tax amount per person	0.020***	0.020***	0.021***	0.023***	0.045***	0.045***	0.048***	0.046***	0.033***	0.030***	0.040***	0.038***	0.000	0.000	-0.000	0.000
	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.005)	(0.004)	(0.008)	(0.007)	(0.007)	(0.007)	(0.001)	(0.001)	(0.001)	(0.001)
Period dummy 1981-2000	-0.005***	-0.005***	-0.003***	-0.004***	-0.004***	-0.004***	-0.002*	-0.002	-0.011***	-0.011***	-0.008***	-0.009***	-0.002***	-0.002***	-0.002***	-0.001***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Period dummy 2001-2020	-0.001	-0.002	-0.001	0.000	-0.011***	-0.011***	-0.012***	-0.008***	-0.005	-0.007	-0.004	-0.002	-0.002	-0.002	-0.004	-0.002
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.008)	(0.008)	(0.006)	(0.008)	(0.003)	(0.003)	(0.003)	(0.003)
Observations	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758
AR(2) test p-value	0.187	0.111	0.112	0.227	0.013	0.015	0.015	0.012	0.007	0.006	0.008	0.011	0.717	0.884	0.705	0.707
Hansen test p-value	0.556	0.557	0.539	0.534	0.536	0.529	0.537	0.545	0.534	0.524	0.522	0.535	0.549	0.570	0.616	0.537

Notes: Clustered and heteroscedasticity robust standard errors are reported in parentheses. Stars indicate statistical significance: * p<0.10, ** p<0.05, *** p<0.01.

Table A2: Analysis results (1960–1980, productive capital stock)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Dependant variable	HDI	HDI	HDI	HDI	Income index	Income index	Income index	Income index	Education index	Education index	Education index	Education index	Life index	Life index	Life index	Life index
Ln total infrastructure	0.196***				0.122***				0.562***				-0.008**			
(productive capital stock per person)	(0.035)				(0.026)				(0.120)				(0.003)			
Ln transport infrastructure		0.153***				0.092***				0.452***				-0.007**		
(productive capital stock per person)		(0.030)				(0.021)				(0.107)				(0.003)		
Ln water and sanitation infrastructure			0.060***				0.047**				0.193***				-0.006	
(productive capital stock per person)			(0.021)				(0.023)				(0.067)				(0.004)	
Ln education infrastructure				0.090***				0.049				0.319***				-0.008**
(productive capital stock per person)				(0.015)				(0.031)				(0.042)				(0.003)
L. dependant variable	0.310***	0.342***	0.774***	0.777***	0.254***	0.275***	0.482***	0.453***	0.251	0.277*	0.728***	0.804***	0.959***	0.959***	0.776***	0.903***
	(0.115)	(0.117)	(0.068)	(0.050)	(0.047)	(0.047)	(0.047)	(0.061)	(0.153)	(0.164)	(0.121)	(0.052)	(0.043)	(0.040)	(0.074)	(0.040)
Ln population	-0.114*	-0.116	-0.084**	-0.053	-0.045	-0.050	-0.016	-0.028	-0.306*	-0.271	-0.350***	-0.198**	0.001	0.001	-0.009	0.003
	(0.067)	(0.081)	(0.039)	(0.034)	(0.075)	(0.077)	(0.070)	(0.062)	(0.180)	(0.217)	(0.115)	(0.078)	(0.005)	(0.005)	(0.008)	(0.006)
Elderly rate (%)	-0.022**	-0.028***	-0.002	0.002	-0.007	-0.012	0.010	0.004	-0.077***	-0.087***	-0.041***	-0.010	0.001	0.001	0.000	0.001
	(0.009)	(0.011)	(0.006)	(0.006)	(0.011)	(0.011)	(0.012)	(0.011)	(0.027)	(0.030)	(0.016)	(0.015)	(0.001)	(0.001)	(0.001)	(0.001)
Urbanization rate (%)	-0.001	-0.001	0.001	-0.000	-0.001	-0.001	0.001	-0.000	-0.003	-0.002	-0.001	-0.001	0.000	0.000	0.000	0.000
	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.004)	(0.005)	(0.003)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Employed in primary industry (%)	0.001	0.001	0.001	0.000	0.001	0.002	0.001	0.000	0.003	0.004	0.004	0.001	-0.000	-0.000	0.000	0.000
	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.003)	(0.003)	(0.005)	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)
Employed in secondary industry (%)	0.001	0.000	-0.001	0.001	-0.000	-0.001	-0.001	0.000	0.004	-0.000	-0.003	0.005*	0.000	0.000	0.000	0.000
	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.004)	(0.004)	(0.005)	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)
Ln local tax amount per person	0.006	0.005	0.041***	0.036***	0.076***	0.073***	0.079***	0.073***	-0.061**	-0.061**	0.058***	0.050**	0.000	0.001	-0.000	0.001
	(0.008)	(0.008)	(0.007)	(0.005)	(0.012)	(0.012)	(0.010)	(0.010)	(0.027)	(0.029)	(0.020)	(0.020)	(0.001)	(0.001)	(0.001)	(0.001)
Time trend	0.009**	0.014***	-0.001	-0.004	0.007*	0.011***	0.001	0.004	0.014	0.025**	0.005	-0.016**	0.001	0.000	0.003**	0.001**
	(0.004)	(0.004)	(0.003)	(0.002)	(0.004)	(0.004)	(0.005)	(0.004)	(0.011)	(0.011)	(0.008)	(0.007)	(0.001)	(0.001)	(0.002)	(0.001)
Square term of time trend	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***	-0.001***	-0.001**	-0.000***	-0.000***	0.000	0.000	0.000	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758
AR(2) test p-value	0.002	0.001	0.001	0.046	0.619	0.649	0.501	0.174	0.004	0.004	0.002	0.075	0.522	0.377	0.087	0.260
Hansen test p-value	0.017	0.015	0.033	0.013	0.010	0.011	0.013	0.011	0.035	0.031	0.026	0.035	0.268	0.199	0.253	0.106

Notes: Clustered and heteroscedasticity robust standard errors are reported in parentheses. Stars indicate statistical significance: * p<0.10, ** p<0.05, *** p<0.01.

Table A3: Analysis results (1981–2000, productive capital stock)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Dependant variable	HDI	HDI	HDI	HDI	Income index	Income index	Income index	Income index	Education index	Education index	Education index	Education index	Life index	Life index	Life index	Life index
Ln total infrastructure	0.048				0.016				0.531**				0.001			
(productive capital stock per person)	(0.059)				(0.060)				(0.211)				(0.010)			
Ln transport infrastructure		0.039				0.044				0.515**				-0.005		
(productive capital stock per person)		(0.068)				(0.083)				(0.243)				(0.010)		
Ln water and sanitation infrastructure			0.020				-0.038				0.181				-0.019*	
(productive capital stock per person)			(0.043)				(0.042)				(0.139)				(0.011)	
Ln education infrastructure				0.024				0.012				0.231**				-0.008**
(productive capital stock per person)				(0.025)				(0.026)				(0.102)				(0.003)
L. dependant variable	-0.472***	-0.271*	-0.493**	-0.604***	0.299***	0.287***	0.281***	0.301***	-0.933***	-0.707***	-0.559***	-1.032***	0.853***	0.800***	0.812***	0.816***
	(0.140)	(0.138)	(0.222)	(0.165)	(0.067)	(0.057)	(0.064)	(0.064)	(0.166)	(0.172)	(0.215)	(0.179)	(0.047)	(0.046)	(0.041)	(0.047)
Ln population	0.209	0.181	0.386***	0.198*	-0.054	0.009	-0.098	-0.079	1.396**	1.596**	1.465***	0.908*	0.020	0.003	0.024	0.034
	(0.133)	(0.164)	(0.139)	(0.115)	(0.088)	(0.130)	(0.122)	(0.105)	(0.567)	(0.680)	(0.393)	(0.487)	(0.019)	(0.026)	(0.023)	(0.022)
Elderly rate (%)	0.008**	0.007*	0.018***	0.009**	-0.005	-0.004	-0.006	-0.005	0.046***	0.045***	0.062***	0.038**	-0.000	-0.001	0.000	0.001
	(0.004)	(0.003)	(0.005)	(0.004)	(0.004)	(0.003)	(0.005)	(0.005)	(0.016)	(0.015)	(0.013)	(0.015)	(0.001)	(0.001)	(0.001)	(0.001)
Urbanization rate (%)	-0.000	-0.001	0.000	0.000	0.002	0.001	0.001	0.002**	0.000	-0.003	0.002	0.003	-0.001***	-0.001***	-0.001**	-0.001***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.004)	(0.004)	(0.005)	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)
Employed in primary industry (%)	0.000	0.001	-0.007	-0.001	0.006*	0.005	0.005	0.006*	-0.027*	-0.027*	-0.026*	-0.028**	0.000	0.000	-0.002	-0.001
	(0.003)	(0.002)	(0.005)	(0.003)	(0.003)	(0.003)	(0.005)	(0.003)	(0.015)	(0.014)	(0.015)	(0.014)	(0.001)	(0.001)	(0.001)	(0.001)
Employed in secondary industry (%)	0.000	0.001	-0.006	-0.001	0.008***	0.008***	0.009**	0.008***	-0.029**	-0.024**	-0.030***	-0.029***	-0.000	0.000	-0.001	-0.001
	(0.002)	(0.002)	(0.004)	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.012)	(0.012)	(0.010)	(0.011)	(0.001)	(0.001)	(0.001)	(0.001)
Ln local tax amount per person	-0.013	-0.021**	0.008	-0.005	0.034***	0.036***	0.027*	0.036***	-0.050	-0.081**	-0.031	-0.016	0.008**	0.007**	0.009***	0.006**
	(0.010)	(0.009)	(0.011)	(0.013)	(0.010)	(0.010)	(0.015)	(0.010)	(0.034)	(0.033)	(0.027)	(0.042)	(0.003)	(0.003)	(0.003)	(0.003)
Time trend	0.009*	0.010*	0.003	0.009**	0.011**	0.009	0.015***	0.011***	-0.075***	-0.066***	-0.054***	-0.064***	-0.000	0.001	0.001	0.001
	(0.005)	(0.006)	(0.005)	(0.004)	(0.005)	(0.007)	(0.004)	(0.003)	(0.023)	(0.024)	(0.016)	(0.020)	(0.002)	(0.002)	(0.001)	(0.001)
Square term of time trend	-0.000	-0.000**	-0.000**	-0.000	-0.000	-0.000	-0.000*	-0.000	0.000*	0.000	0.000	0.001**	0.000*	0.000**	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758
AR(2) test p-value	0.005	0.019	0.001	0.003	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.217	0.888	0.626	0.158
Hansen test p-value	0.017	0.019	0.014	0.015	0.005	0.005	0.005	0.005	0.010	0.011	0.015	0.009	0.027	0.028	0.016	0.038

Notes: Clustered and heteroscedasticity robust standard errors are reported in parentheses. Stars indicate statistical significance: * p<0.10, ** p<0.05, *** p<0.01.

Table A4: Analysis Results (2001–2020, productive capital stock)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Dependant variable	HDI	HDI	HDI	HDI	Income index	Income index	Income index	Income index	Education index	Education index	Education index	Education index	Life index	Life index	Life index	Life index
Ln total infrastructure	0.208**				0.138				0.390**				0.037			
(productive capital stock per person)	(0.089)				(0.121)				(0.160)				(0.028)			
Ln transport infrastructure		0.198**				0.195				0.387**				0.029		
(productive capital stock per person)		(0.089)				(0.134)				(0.171)				(0.026)		
Ln water and sanitation infrastructure			0.045				-0.236*				0.474***				-0.030**	
(productive capital stock per person)			(0.050)				(0.124)				(0.142)				(0.012)	
Ln education infrastructure				0.165**				0.120				0.292**				0.013
(productive capital stock per person)				(0.065)				(0.117)				(0.141)				(0.013)
L. dependant variable	-0.532***	-0.561***	-0.297***	-0.354***	-0.018	-0.075	0.036	0.042	0.630***	0.629***	0.686***	0.508***	0.387***	0.401***	0.730***	0.575***
	(0.081)	(0.085)	(0.105)	(0.086)	(0.070)	(0.073)	(0.085)	(0.081)	(0.097)	(0.106)	(0.107)	(0.097)	(0.121)	(0.103)	(0.082)	(0.080)
Ln population	0.253	0.260	-0.010	0.112	0.035	0.125	-0.493***	-0.017	0.320	0.341	0.390	0.085	0.009	0.004	-0.079***	-0.030
	(0.169)	(0.174)	(0.093)	(0.097)	(0.192)	(0.239)	(0.186)	(0.141)	(0.274)	(0.287)	(0.239)	(0.186)	(0.036)	(0.040)	(0.019)	(0.018)
Elderly rate (%)	0.002*	0.002**	0.002**	0.003**	0.003**	0.002	0.002	0.003***	-0.004**	-0.004**	-0.004*	-0.001	-0.000*	-0.000***	-0.001***	-0.000*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Urbanization rate (%)	0.001	0.000	0.002**	0.002	0.000	-0.001	0.000	0.000	0.001	0.000	0.002	0.003*	0.000	0.000	-0.000	0.000
	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Employed in primary industry (%)	0.001	-0.000	0.001	0.001	0.012***	0.013**	0.015***	0.011***	0.014**	0.012*	0.016***	0.009	0.005***	0.004***	0.004***	0.004***
	(0.003)	(0.004)	(0.002)	(0.003)	(0.004)	(0.005)	(0.004)	(0.004)	(0.006)	(0.006)	(0.006)	(0.006)	(0.001)	(0.001)	(0.001)	(0.001)
Employed in secondary industry (%)	-0.002	-0.002	-0.004	-0.008***	0.016***	0.019***	0.009**	0.011***	-0.002	-0.002	0.005	-0.017***	0.001*	0.001*	0.001***	0.001
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.004)	(0.005)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.001)	(0.001)	(0.000)	(0.001)
Ln local tax amount per person	0.063***	0.065***	0.061***	0.071***	0.036***	0.039***	0.058***	0.041***	0.052***	0.054***	0.029**	0.086***	-0.002*	-0.002**	-0.001***	-0.002
	(0.007)	(0.007)	(0.006)	(0.006)	(0.011)	(0.011)	(0.009)	(0.009)	(0.011)	(0.012)	(0.013)	(0.012)	(0.001)	(0.001)	(0.000)	(0.001)
Time trend	0.007	0.008	0.009	-0.006	0.040***	0.043***	0.050***	0.029*	-0.008	-0.006	-0.004	-0.034*	0.009***	0.009***	0.009***	0.007***
	(0.009)	(0.008)	(0.007)	(0.010)	(0.008)	(0.008)	(0.007)	(0.016)	(0.012)	(0.012)	(0.010)	(0.019)	(0.002)	(0.002)	(0.002)	(0.002)
Square term of time trend	-0.000	-0.000	-0.000	0.000	-0.000***	-0.000***	-0.000***	-0.000*	0.000	0.000	0.000	0.000*	-0.000***	-0.000***	-0.000***	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758	2,758
AR(2) test p-value	0.853	0.694	0.773	0.128	0.000	0.000	0.000	0.000	0.024	0.021	0.007	0.046	0.023	0.021	0.195	0.066
Hansen test p-value	0.013	0.012	0.009	0.012	0.004	0.004	0.004	0.005	0.010	0.011	0.010	0.011	0.135	0.170	0.038	0.077

Notes: Clustered and heteroscedasticity robust standard errors are reported in parentheses. Stars indicate statistical significance: * p<0.10, ** p<0.05, *** p<0.01.

Abstract (in Japanese)

要　約

インフラは、人間の社会活動の幅広い範囲にわたって影響を及ぼす。本論文では、日本の都道府県別人間開発指数（HDI）の長期パネルデータ（1960-2020）を新たに構築し、その分析を通じて、インフラが人間の豊かさの度合い（human well-being）にもたらす影響を検証する。分析の結果、インフラは総じてHDIに正の影響を与えている。運輸・水衛生・教育インフラ合計の影響はHDIに対して有意に正であり、インフラストックが１％増えるごとにHDIは0.016伸びることが明らかにされた。この正の影響は、分野別でみた場合、運輸インフラによるところが大きく、その経路は、人や企業の経済活動の活発化を通じた生産性の向上や経済成長への貢献、学校へのアクセスの改善を通じた進学率向上への寄与である。但し、運輸インフラは平均余命に対しては負の影響を示しており、その経路の可能性としては、1960・70年代における交通事故や大気汚染の深刻化が考えられる。以上の分析結果は、インフラと人々の豊かさ（human well-being）との大局的な関係の明確化に貢献するものである。また、日本のインフラの評価をより多面的なものにするとともに、増えつつある新興国のインフラ投資に対しても知見を提供する。

キーワード：　インフラ、公共資本、人間開発指数、日本、運輸、水衛生、教育