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Japanese social capital and social vulnerability indices: Measuring drivers of community resilience 2000–2017

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ABSTRACT

Recently, scholars have turned to publicly available data to measure the resources and vulnerability of communities in the face of disasters [1,2]. However, when measuring community resilience to climate change, custom surveys of social capital are often costly or unfeasible to conduct for every community in a country. Despite suffering numerous disasters in the last thirty years, Japanese disaster scholarship lacks municipality-level measures of social capital and social vulnerability. This study uses publicly available data to develop new bonding, bridging, and linking social capital indices, paired with a new social vulnerability index, available for each of Japan's 1741 municipalities, using principal component analysis and validation techniques. Scholars and policymakers can directly apply these indices to evaluate the social capital or vulnerability of specific communities, compare across multiple communities, model their effect of outcomes, and better prepare for future disasters.

1. Introduction

While communities are increasingly preparing themselves better to adapt and respond to floods, storms, and droughts caused by climate change, some communities prove more resilient than others [3]. Scholars have developed several indices to measure aspects of resilience, including social capital (Aldrich & Kyne 2020), social vulnerability [2], and infrastructural preparedness [4]. These indices have been largely focused on the US. Others have expanded indices to Brazil, Portugal, Italy, Bangladesh, and Nepal, among others [5–9,81]. Finally, others have used surveys and interviews to document and contextualize accounts of social capital and vulnerability in specific communities [10,45,73,87]. However, Japanese communities lack a comprehensive measure of social capital and social vulnerability for all municipalities, despite regularly suffering major disasters, including floods, storms, earthquakes, and tsunamis.

This paper introduces a methodology to create the Japanese Municipal Social Capital Index and Social Vulnerability Index, for every year from 2000 to 2017. This adapts the methods of Kyne and Aldrich's [1] Social Capital Index (SCI) for US counties and Cutter and colleagues' [2] Social Vulnerability Index (SoVI). Following their models, I generate five indices, each scaled from 0 to 1, where 0 indicates weakest social capital or vulnerability and 1 equals strongest social capital or vulnerability among all 1741 Japanese municipalities. These indices include an overall social capital index, separate bonding, bridging, and linking social capital indices, and a social vulnerability index. These indices use only publicly available data from municipal, district, or prefectural level census and election data sources. This new set of measures to describe the social capital and social vulnerability of communities in Japan can help policymakers evaluate their potential resilience to hazards and aid researchers studying their effects on crisis outcomes.

2. Literature review

Since the Great Hanshin Earthquake devastated the metropolitan area of Kobe in 1995, the Japanese central government, prefectural governments, and local governments have made disaster resilience a key goal. After Kobe, officials realized that governments face extremely limited capacity during disasters, relying on preparations or, better yet, community engagement [11]. Even so, initial attempts towards resilience after Kobe focused on infrastructure preparedness, but the failure of seawalls and warning systems to guard against the 2011 tsunami, earthquake, and nuclear disaster reignited interest in community-level factors in resilience [12]. This is because disasters are not natural but man-made, through decisions of where and how to build, whether or not to safeguard the most vulnerable members of society from possible consequences [13,14,84], and whether to engage communities in response [15,16]. Recovery from shocks and hazards can be measured

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using the number of excess deaths in the months and years following crisis [17,18], how many people leave or return after a crisis [19,20,21,78], or how much they rebuild [22], in addition to numerous other social and economic measurements (eg. Ref. [23]). Researchers, policymakers, and first responders increasingly point to two root causes of community resilience: social vulnerability and social capital. Below, I review the literature on each and their applicability to disaster outcomes.

2.1. Social vulnerability

Community resilience to disasters depends considerably on the social vulnerability of communities, in terms of age, gender, income, and minority status, among others [24–28]. Concepts like race, ethnicity, class, religion, inequality, and sexuality have been shown to greatly deter resilience outcomes like evacuation or recovery, as these level additional barriers on residents, such as concern about discrimination or lack of financial resources [28–30]. Scholars highlight that women frequently bear heavy burdens during crisis, frequently taking care of family members and sometimes leaving jobs because of it [27,31,82]. In addition, older residents, residents under care at hospitals or nursing, or disabled residents frequently have limited mobility and require close care, making them more vulnerable to and after disaster [32]. Finally, livelihood and unemployment are also key indicators of social vulnerability, frequently used in indices, as employees of the manufacturing sector tend to lose jobs due to plant closures after disasters, while high unemployment in general is a major deterrent to acquiring capital for rebuilding [2,8,9]. In summary, based on the literature, communities tend to be less resilient and more vulnerable to the effects of disaster if they have poorer residents, high unemployment, higher shares of racial, ethnic, and religious out-groups, with more women, with older populations, with more dependents, and more employment in vulnerable industries. However, as I describe below, a community's capacity for resilience depends on more than just its traits of vulnerability, but also the social structure of the community.

2.2. Social capital and community resilience

In addition, a key reason why some communities evacuate from, respond to, and recover from disasters better than others is the strength of social ties in a community [16,23,33,34,83]. Social capital is a key community resource that can help residents share physical, financial, or social resources [35,39,41]. In non-crisis times, strong social networks can help residents find employment [36], improve economic development [37], motivate students and improve educational outcomes [38], improve health outcomes [39,40], and help residents obtain better public goods from local officials [88,89]. But in times of crisis, residents can utilize their social ties to obtain or generate key public goods themselves, via three types of social capital: bonding, bridging, and linking ties.

2.2.1. Bonding social capital

Bonding social capital refers to tight bonds between "people who see themselves as being similar" [39]; p. 654) and in the same social group, such ties as between friends and family [41]. In practice, bonding social capital is accompanied by high degrees of similarity in demographics, such as race, ethnicity, class, age-cohort, or family, and attitudes, such as religious affiliation or political partisanship [39,42–44]. These shared traits facilitate social cohesion and trust within groups [38]. These in-group ties jumpstarted response to Hurricane Maria in Puerto Rican communities, encouraging neighbors to share tools and machines and dig out structures collapsed by landslides [85], and helped close-knit African American residents in New Orlean's 9th Ward flee during Hurricane Katrina [45].

In Japan, after the Tokyo Earthquake in 1925, neighbors helped each other sort through debris to reconstruct shelters, while pawn shops allowed poor residents to trade in tangible valuables in exchange for key necessities, which banks would not accept [21]. Bonding ties might lead residents not to evacuate, because they and members of their social network support each other, share shelter when hazards strike, and aid in rebuilding [46,47]. However, bonding, in-group ties might reduce overall access to mutual support and resources, because individuals share just with those with whom they have strong bonding ties – those within the same class and race [23,48]. In worst case scenarios, empowered in-groups may discriminate against out-groups and commit acts of political violence [49,50], as occurred in the riots against Koreans after the Tokyo Earthquake in 1923 [21]. This effect has been called the Janus-faced nature of social capital [21,51].

2.2.2. Bridging social capital

In contrast, bridging social capital connects residents from different social groups [16,39,45]. These ties are commonly built in the workplace [36], unions [15], temples, synagogues, mosques, and churches [52,71,73], and volunteer groups (Putnam 2000), such as neighborhood associations [53] or parent-teacher associations [54]. These civil society associations bring together people from different social cliques in terms of race, class, religion, age, and gender, building bridging, inter-group ties [16,88,90].

Unlike bonding social capital, which trends closely with homophily, heterophilous communities do not always have strong bridging social ties, leading to social divisions, inequity, and discrimination (Elliott 2010; [50]. Instead, the inter-group ties built by civil society associations facilitate the spread of information, trust, reciprocity, and shared stake in one's community, all of which tend to increase civic engagement [90], reduce inter-ethnic conflict [50], and improve access to resources across racial and ethnic lines [45]. As a result, rates of civil society associations correlate positively with population recovery after disasters [21].

In the present day, most neighborhood blocks and apartment buildings have their own neighborhood associations (*chonaikai*) - resident groups akin to homeowners' associations that can be activated to check in with local residents, share disaster preparation protocols, encourage evacuation, collect signatures for petitions or rebuilding efforts, or engage in volunteer efforts [53,55]. A key reason for their importance is that the Japanese legal code did not permit civil society organizations to incorporate as nonprofits until 1997, meaning that they stayed local and small-scale [56]. In addition, in Japan, volunteer associations, environmental organizations, food cooperatives, and women's associations are powerful sources of bridging capital, propelling residents into civic action [57,58]. Bridging capital has been linked to numerous positive recovery outcomes after disaster [17,18].

2.2.3. Linking social capital

Finally, linking social capital represents vertical connections between residents and public officials. Citizens with stronger linking ties with their officials see better delivery of public goods [89], especially after disasters [59,60]. Linking social capital tends to interact with other kinds of social capital to produce key recovery outcomes. For example, after Kobe, For example, after the 1995 Kobe earthquake, wards with strong, organized civil society organizations petitioned city planners for recovery strategy that fit their needs, not developers [22]. Here, communities leveraged their linking and bridging social capital to improve recovery. In contrast, in after New Orleans, neighborhoods with strong bonding and linking ties were able to petition their local officials and avoid hosting controversial FEMA trailers, but this forced *other* communities to host them instead [61]. And after Japan's 3/11 disaster, communities with stronger linking ties consistently saw lower mortality rates and better recovery outcomes [12].

In summary, community resilience to shocks and hazards is strongly related to these three aspects of social capital, as well as to social vulnerability. Social capital and social vulnerability in tandem, especially, are powerful predictors of disaster outcomes, and should be studied in tandem [10,62–64]. Below, I outline a methodology to measure these concepts for Japanese municipalities.

3. Research design

This study generates five indices, describing overall social capital, bonding, bridging, and linking social capital, and social vulnerability, for all 1741 Japanese municipalities annually between 2000 and 2017. I draw from 41 publicly available variables. Below, I describe the basic methods used, indicators employed, validation measures, and applications.

3.1. Index methods

This study constructs its five indices by acquiring several variables that describe different aspects of the concept, scaling them from 0 to 1, where 0 indicates weakest social capital or vulnerability and 1 indicates strongest, and combining these each into an index. This study mirrors Kyne and Aldrich's [1] approach for its social capital indices and Cutter et al.'s [2] approach for its social vulnerability index. I use indicators as similar as possible for each, and substitute where necessary due to lack of available census data.

I test two different methods of making each index, which I term 1) *average of averages* and 2) *average of principal components*. The first technique, used by Kyne & Aldrich [1], averages variables together into a subindex (bonding, bridging, or linking capital), and then averages the subindices together into an overall index. This works well when each variable represents an equally important but slightly different aspect of the overall concept; it is easy to apply multiple imputation to fill in missing data when using this technique. In contrast, when some variables represent overlapping trends or aspects of the overall concept, averaging them might *over-weight* those trends in the final index.

Instead, the second technique uses principal component analysis (PCA) to distill many variables into a smaller number of relevant principal components, each representing a distinct trend in the data. Each component explains a certain percentage of the overall concept; I combine components until I explain over 80% of the variation or more, in keeping with Cutter et al.'s [2] process. Having generated principal components, I then rescale those components from 0 to 1 and average them to create an index. I compare multiple imputation strategies for missing data and different rotations for principal component analysis.

These competing advantages begs a question: does the *average of averages* or *average of principal components* generate better social capital and social vulnerability indices? I create and run validation models for *both kinds of indices* to test which more accurately produces the expected effects. Both kinds of indices draw from the indicators discussed below.

3.2. Bonding social capital components

This study uses 7 components to represent bonding social capital, building on Kyne & Aldrich's [1] methodology. Kyne and Aldrich used race and ethnic similarity, negative measures of bonding capital computed by calculating how fractionalized that community is into different racial and ethnic groups. The Japanese census does not collect the percentage of Japanese citizens by race or ethnicity, but they do indicate Japanese citizens vs. non-Japanese cities. Since most Japanese communities are relatively ethnically homophilous (at least compared to their American peers), I focus on *national similarity* in terms of fractionalization between Japanese and foreign residents.

Further, I add *religious similarity* as an important component of bonding capital. Data on the number of Shinto and Buddhist residents is unavailable - and notoriously hard to estimate, since most Japanese identify as both Shinto and Buddhist, but many are not so-to-speak practicing Buddhists. However, the state records the number of Christians and members other religious minorities, and so I calculate fractionalization between minority religious and the rest of society. Because racial stratification is rare, I do not calculate race-based income similarity.

Next, I measure *educational similarity* the same as in past studies, using the negative absolute difference between the percentage of total population with college education and the percentage of total population with less than high school education. Then, because income categories are unavailable in the census, instead of gender income similarity, I measure *gender employment similarity*, based on the negative absolute difference between men's employment similarity and women's employment similarity. Using the same component parts, I also measure *overall employment similarity* by finding the absolute difference between the percentage of employed and unemployed members of the labor force.

Next, I measure *communication capacity* via proxy. While the US measure used the percentage of residents with a landline, this was unavailable. Instead, the Japanese census collects whether residents have an NHK television contract (the Japanese public broadcasting station) or not, but not whether residents have access to a phone. This is a good measure of communication connectivity, because households *without* NHK probably do not have phone service either, based on the ubiquitous access to NHK in most parts of Japan. Finally, I measure *age similarity* the same way as past studies, using the share of residents below age 65. All measures come from the municipal level.

3.3. Bridging social capital components

Next, I use 8 indicators to create a bridging social capital index. The US measure for bridging capital relied on, in addition to other factors, three indicators of social embeddedness: charitable ties, fraternal ties, and union ties.

While they measure charitable ties using the share of residents who are members of a charitable organization, this is unavailable in the Japanese census. Additionally, Japanese civil society is much more localized than US civil society [56], meaning that participation in charitable organization is rarer, or at least different. Instead, I measure *social embeddedness* via *charitable ties* through the amount people volunteer (rate of residents who volunteer per prefecture). Next, to measure *social embeddedness* via *fraternal ties,* this study's proxy differs from the US measure, the ratio of members in a fraternal association, which is unavailable. Instead, I measured the number of community centers and public libraries per capita at the municipal level. While fraternal associations are rare in Japan, local neighborhood activities at community centers and libraries are numerous.

Then, to measure *social embeddedness* via *union ties*, I measured the number of unions per capita at the prefectural level. Finally, *civic organizations* and *religious organizations* remained as important measures of bridging capita. As equivalent to Kyne and Aldrich's measure, the number of civic organizations per 10,000 persons, I used the number of registered nonprofit organizations per capita at the prefectural level to capture the strength of *civic organizations* per municipality. Then, I captured the number of registered *religious organizations* per capita at the prefectural level.

Finally, to supplement this index, I incorporate voter turnout in prefectural elections and in Lower House elections to measure civic engagement, an important form of bridging social capital. In summary, I used 4 municipal level measures and 4 prefectural level measures, based on data availability.

3.4. Linking social capital components

Next, I used 6 indicators to approximate linking social capital. The US measure for linking capital captures local, state, and federal government linkages, and political linkages and political activism. I used municipal, district, and prefectural measures to reflect these concepts as closely as possible.

For local government, past studies used the percentage of total *local* *government employees* working for local government. To approximate this, I used the number of municipal government employees per capita at the municipal level. I also supplemented this with the number of *police* per capita at the prefectural level, to represent the emergency services personnel they could connect with. For state government, past studies used the percentage of total *state employees* working for the state governments; I used the number of prefectural government employees per capita in each prefecture and the percentage of the vote that went to the party in power in prefectural elections [91]. For federal government, although others used the percentage of total federal employees working for the federal agencies there, I used the percentage of the *vote that went to the party in power* in the Lower House election during the most recent election [65]. I also supplemented this with the percentage of the vote that went to the party in power in prefectural elections. This represents how much pull each community has on the party in power, and how much national level elected officials might want to cater to that community in the future. Since Japanese national agencies are concentrated in Tokyo, and branches are not always distributed throughout Japan, an electoral variable is a better representation of linking capital here.

For political linkages and political activism, past studies used the percentage of the total voting-age population who are eligible for voting, and the percentage of residents who attended a political rally, speech, or organized protest in the past year. Since this information was unavailable at the municipal level, I instead used the number of *prefectural assembly members* per capita at the prefectural level to approximate political linkages, and the percentage of the vote that went to the party in power in *prefectural elections*. While these differ slightly from the original design, they also more clearly represent the way that residents call on their officials. In summary, this measure used one municipal level variable, two district level variables, and three prefectural level variables to approximate linking capital (See all social capital indicators in Table 1).

3.5. Social vulnerability index

Next, this study aims to fill a second gap in available resources for disaster scholars in Japan by producing a social vulnerability index for Japanese municipalities, using 19 indicators (see Table 2). Cutter et al.'s SoVI contains the following 13 concepts: race and ethnicity, age, family structure, socioeconomic status, education, gender, renters, residential property, social dependence, special-needs populations, medical services and access, and occupation, employment loss, totaling 29 indicators [2]. Proxies for these were then used to create principal components via PCA.

I match this process as closely as possible, using two different strategies. In the first strategy, I group indicators into six larger groups: *demographics, population structure, socioeconomic status, employment, housing, and social dependence.* For *demographics*, I use the percentage of non-Japanese residents (the highest level of detail available from the census) to capture ethnicity, and to represent gender, the share of women in the population, the percentage of women in the labor force, and the number of single-mother households per capita. For *population structure*, I use the median age, the percentage of vulnerable-age-residents, meaning under age 5 or over age 65, and the number of single-parent households per capita. For *socioeconomic status*, I use income per capita in thousands of yen, the percentage of elementary school graduates, and the number of automobiles per capita. For *employment*, I use the unemployment rate, and to represent employment in vulnerable industries, I use the percentage of employees working in the primary sector (raw materials) and the percentage working in the secondary sector (manufacturing). To represent *housing*, I use residential land prices.[1] Finally, for *social dependence*, I use municipal expenditures on social assistance per capita, the percentage of nursing home residents, the share of the population lacking health insurance, the medical exam rate, and the number of hospitals per capita.

After averaging indicators to make indices for these and rescaling them from 0 to 1, where 0 indicates minimal vulnerability and 1 equal maximum vulnerability, I average these to make an overall index. In the

Table 1
Social capital index indicators.

Index	Concept	Level	Effect	Indicator
Bonding Social Capital	Nationality similarity	municipal	–	Nationality Fractionalization (Japanese vs. Foreign Population)
	Religious similarity	municipal	–	Fractionalization by Religious Minority (Religious Minorities vs. Non-Minority Residents)
	Educational equality	municipal	–	Negative absolute difference between percentage of total population with college education and percentage of elementary school graduates
	Gender employment similarity	municipal	–	Fractionalization of employment equality by gender (Women's vs. Men's Employment Equality)
	Employment equality	municipal	+	Absolute difference between % of employed and % of unemployed labor force
	Communication capacity	municipal	+	television broadcast reception contracts per capita
	Non-Elder population	municipal	+	% of total population below 65 years of age
Bridging Social Capital	Social embeddedness: civil society participation and norm adoption	municipal prefectural	+	Volunteer Participation Rate (over age 10) Voter Turnout in Prefectural Elections Voter Turnout in Lower House Elections
	Social embeddedness: neighborhood ties	municipal	+	Community Centers per capita Libraries per capita
	Social embeddedness: union ties	prefectural	+	Unions per capita
	Civic Organizations	prefectural	+	Nonprofit Organizations per capita
	Religious organizations	prefectural	+	Religious organizations per capita
Linking Social Capital	Local Government Linkage	municipal	+	Local government employees per capita
	State government linkage	prefectural	+	Prefectural government employees per capita Prefectural police per capita
	Federal government linkage	district	+	% of vote for Ruling Party in House of Reps elections
	Political Linkage: political activities	district	+	Prefectural Assembly members per capita % of vote for Ruling Party in Prefectural Elections

[1] Unlike the US census, the Japanese census provides housing data for only some cities; as a result, I infer based on residential land prices.

Table 2
Social vulnerability index indicatoxrs.

Component	Concept	Effect	Indicator
Demographics	Race & Ethnicity	+	(%) Non-Japanese Residents
	Gender	+	(%) Women
		+	(%) Women in Labor Force
		+	Single-mother households per capita
Population Structure	Age	+	Median Age
		+	% Ages 0–5 or +65
	Family Structure	+	Single-parent households per capita
Socioeconomic Status	Socioeconomic Status	–	Income per capita in thousands of yen
	Education	+	(%) Elementary School Graduates
	Mobility	–	Automobiles per capita
Employment	Employment Loss	+	Unemployment Rate
	Employment in Vulnerable Industries	+	(%) Employees in Primary Sector
		+	(%) Employees in Secondary Sector
Housing	Residential Property/ Renters	+	Residential Land Prices (yen/m2)
Dependence	Social Dependence	+	Municipal Spending on Social Assistance per capita
	Medical Services and Access	+	(%) Uninsured
		–	Medical Exam Rate
		–	Hospitals per capita
	Special-needs population	+	(%) Nursing Home Residents

second strategy, I use PCA to identify principal components of vulnerability, rescales them, and then average them overall. I select the top principal components that explain at least 80% of the variation in the data, usually nearly 90%.

3.6. Missing data

However, some indicators were missing data. For example, many indicators are not collected annually. For these, I filled in missing years with the most recent year an indicator was collected. In the case of some key variables, variables only started being collected at some year after 2000. In these cases, rather than lose the information, I backfilled these variables with this year. While it is possible that these values changed slightly over time, this index relies on the fact that most index measures do not change dramatically over time. After filling in missing years, these indices only used variables missing less than 10% of data points in any given year; in reality, only residential land prices and voteshare data were missing 8–9% of data points, while all other variables were missing less than 5% of data. However, these were key concepts to include, and so for every index, I compared three imputation strategies, including mean imputation, mean imputation by prefecture (where I imputed the mean value from towns within the same prefecture), and multiple imputation. The available variable-years and how much data was missing for each are available in the replication code.

3.7. Rotation methods for principal component analysis

Further, I created several different *versions* of the PCA indices to examine whether an index performed better in validation tests given a specific rotation method. Any principal component analysis can generate a slightly different index depending on which method for rotating values is used; rotation methods are useful because they can help identify the simplest set of components in a dataset of variables [66,67]. Rotation methods can be separated into four types, including orthogonal rotations like *varimax* and *quartimax* and oblique rotations like *oblimin* and *promax*. Orthogonal rotations are preferred if principal components are uncorrelated, meaning there are no principal components with a Pearson's r correlation coefficient of 0.32 or higher; if so, olbique rotations are receommended [68,86].

In the data, most principal components were correlated, required oblique rotations (oblimin and promax). The only exceptions were the linking social capital index (all imputation styles) and the social vulnerability index (only mean imputation by prefecture), for which I compared orthogonal rotations (varimax and quartimax). To compare social capital and vulnerability indices by imputation style and eligible rotation methods, I conducted 135 rounds of 5 validation models each, which I describe below, selecting the combination of indices which performed best in validation models and descriptive tests.

3.8. Validation models

This study uses five ordinary least squares (OLS) validation models to test the efficacy of these indices. I examine all towns which reported damage from Japan's 2011 earthquake and tsunami, tracking key recovery outcomes in the years 2011–2016 following the 2011 disasters, totaling 1104 town-years, and use these indices to predict five kinds of disaster recovery outcomes. This produced a balanced panel dataset, and I applied annual fixed effects to appropriately account for variation among cities over time. (Random effects could not be computed, due to too few time-steps, and fixed effects better represents the study's aim to control for the effect of time on index scores.) These outcomes modeled include annual change in death rates, sheer death rates, change in out-migration rates, sheer out-migration rates, and change in spending rates on public works.

I set 7 benchmarks by which to assess these indices. Each index passed at least 6. First, we would expect more socially vulnerable towns to be positively associated with poor disaster outcomes, seeing high 1) death rates and 2) high outmigration rates afterwards. In contrast, we would expect that bridging social capital is associated with *changing disaster recovery outcomes, such as* 3) decreases in death rates and 4) outmigration rates, since strong bridging ties have been shown to improve mortality and social cohesion [12,18]. Disaster struck towns frequently face outmigration, especially vulnerable communities, but strong social ties can abate the decline of these towns. In particular, 5) bridging ties help communities share resources, reducing outmigration rates. We would expect that bonding social capital, on the other hand, might actually 6) boost outmigration after controlling for other effects, as suggested by scholars [23,51]. Finally, we would expect linking capital would lead to 7) decreasing spending on public works, because residents with strong linking ties often petition their local officials to invest in community development and economic development *instead* of spending on infrastructure (see Table 3).

This both a) demonstrates the applicability of these indices and b) validates the measures, helping us determine whether the *average of averages* or *average of principal components* approach works better. For each of these 5 outcomes, I model 135 different combinations of indices based on method (averages or PCA), imputation style (mean, mean by prefecture, or multiple imputation), and rotation style (where applicable, oblimin, promax, varimax, or quartimax). This totals 675 models, which can be seen in the replication code. Then, I selected only the

Table 3
Expected effects by outcome & index.

Outcome	Bonding Social Capital	Bridging Social	Linking Social	Social Vulnerability
Change in Death Rates		-		
Death Rates				+
Change in Outmigration Rates		-		
Outmigration Rates	+	-		+
Change in Spending Rates on Public Works			-	

combination of indices in which each expected association was found. These expected associations, described above, are highlighted in Table 3. I compared both combinations within imputation styles (mean imputed social capital and mean imputed social vulnerability) and between imputation styles (mean imputed social capital vs. multiply imputed social vulnerability).

I look for descriptive evidence of associations, statistically significant or not, although strong, statistically significant effects between the $p < 0.001$ and $p < 0.10$ levels are especially strong endorsements of the quality of an index.

Finally, I apply a series of basic controls to these validation controls, to make sure that the effects sought are not due to population, infrastructure (approximated by spending on public works per capita), disaster deaths or damage, whether the town was directly hit by the tsunami or not, or traits specific to each year. For death rates and outmigration rates, which are right-skewed variables, I applied a log-transformation to account for heteroskedasticity common in models of right-skewed outcomes. These models are meant to demonstrate effects with the fewest control variables possible, and are not expected to explain *all variation* in the outcome. However, all mixed models deliver R2 between 0.24 and 0.60, indicating that a sizable amount of variation is explained by these variables and controls alone. No problematic multicollinearity was observed, with variance inflation (VIF) scores well below 10, the threshold for problematic multicollinearity, and exclusively under 2.5, the gold standard, in our final models.

4. Results

This study generated annual social capital and vulnerability indices over 17 years from 2000 to 2017. As described further below, I find that the *average of averages* approach with mean imputation works best for social capital measures, while the *average of principal components* with mean imputation and promax rotations produces the best social vulnerability indices. I visualize the final social capital indices in Fig. 1.

This study finds that most communities have high bonding social capital scores (0.6–0.8), while most communities have middling bridging and linking scores (0.2–0.4). While the shape of overall social capital has not changed dramatically over time, we see that linking social capital and bridging social capital have. Between 2010 and 2014, considerable variation occurred, perhaps representing disruption after the 2011 triple disaster. This effect occurs to bonding social capital indices as well.

I modeled five different recovery indicators to validate whether averaging components or averaging principal components, and which of my 3 imputation strategies and 4 PCA rotation methods, produce better indices of social capital and social vulnerability. This process produced 24 index combinations which produced the correct associations for 5 out of 7 benchmarks. No indices matched every benchmark; the most common association not found was linking social capital's negative effect on change in spending on public works. For final consideration, I examined only those combinations which included at least one correct association per concept (bonding, bridging, linking, and vulnerability), which left only two index combinations, numbers 3 and 132. Indices #3 contains a set of mean imputed indices, where social capital variables were averaged and vulnerability was made via PCA with promax rotations. Indices #132 contain a set of multiply-imputed indices, all made with PCA. Bonding and bridging were made with promax rotations, while linking was made with varimax rotations. Vulnerability was made with promax rotations.

However, as shown in Appendix Figure A3, Indices #3 contained both one correct association per concept and per outcome, whereas Indices #132 failed to predict change in outmigration rates correctly. As a result, I selected Indices #3 as the final social capital and vulnerability indices. Overall, a mixed approach best reproduced expected effect, where I used the *average of averages* to generate social capital indices but the *average of principal components* for social vulnerability. This is not unsurprising; while each social capital indicator represents mostly distinct forms of civic engagement or social life, these vulnerability indicators overlap considerably, making PCA preferable. I report the principal components used for social vulnerability in Appendix Table A3. Further, descriptive bivariate correlations in Appendix Figure A4 show that each of the final indices correlate well with their original components. Finally, I report fixed effects OLS validation models for both Indices #3 and #132 in Appendix Table A1, and I report validation models for the final indices (#3) in Appendix Table A2, including a set of models with just social capital overall instead of bonding, bridging, and linking social capital. These validation tests found that when modeling mortality rates, bridging capital generated a strong negative effect. For example, communities with higher social vulnerability scores saw higher death rates and outmigration rates after

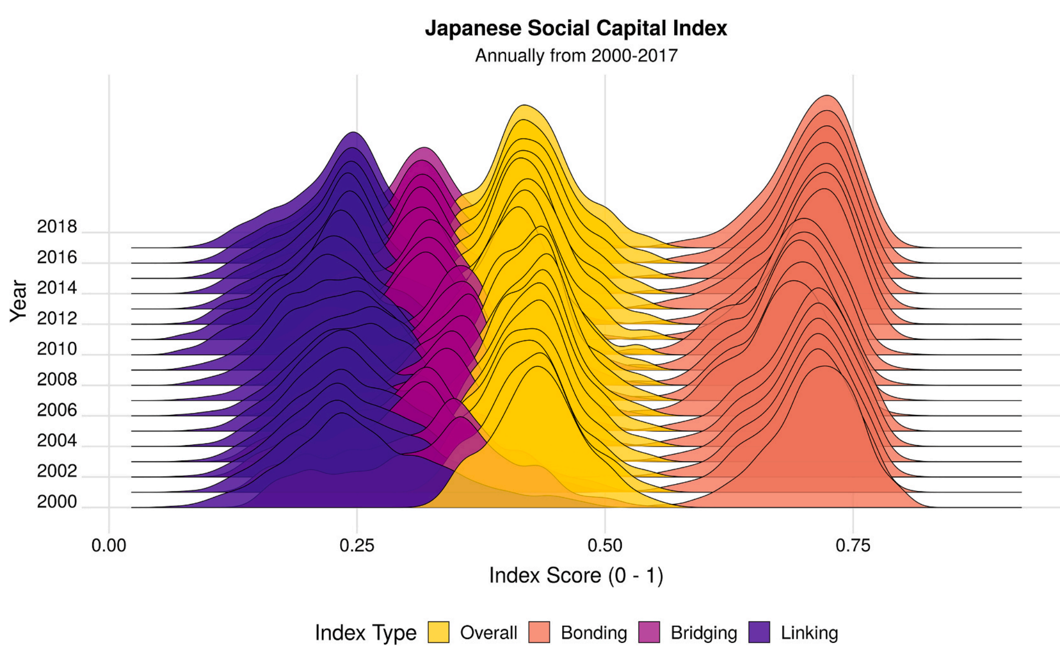

Fig. 1. Shape of Japanese social capital indices over time.

disaster. Communities with strong bonding social capital, on the other hand, saw higher outmigration rates, but those with strong bridging ties saw less outmigration; similarly, albeit not statistically significant, communities with bridging ties saw a decrease in changing outmigration rates over time, while communities with strong bonding social ties saw an increase. This matches past literature on the Janus-faced nature of social capital; it is an important sign that these indices identifies it correctly [51]. Bridging ties are necessary to turn the tide of outmigration after disasters, as shown by the cases of Mano and Mikura wards in Kobe after the 1995 quake [21,83]. Further, linking social capital correctly was associated with a decrease in spending on public works after disaster. Its effect is consistent with my expectation that towns with strong linking ties tend to focus on different kinds of recovery, not just infrastructure, and theoretically consistent with the literature. However, bridging ties showed a positive effect, indicating that towns with stronger bridging ties can motivate reconstruction. Only a mixed approach consistently reproduced the right effects; a completely average-based approach or PCA-approach did not. Finally, the models with overall social capital contrast well with the social capital subtype models. While each subtype shows clear expected positive or negative associations, social capital overall is associated with by positive and negative disaster outcomes, highlighting well the dark-side of social capital [21,49]. This underscores the importance of using narrower indices, namely these bonding, bridging, and linking indices, to distinguish how different types of social capital shape response and recovery.

5. Discussion

This study generated five indices for social capital, bonding, bridging, and linking social capital, and social vulnerability for Japanese municipalities from 2000 to 2017. Above, these measures correctly demonstrated statistically significant effects on key community resilience outcomes. These indices can be used as a tool for identifying communities uniquely vulnerable due to high social vulnerability *and* a dearth of social capital. Below, I discuss the implications of these indices through two descriptive charts.

5.1. *Trends in social capital and social vulnerability*

To further discuss these indices, I visually compare the relationship between indices in aggregate over 17 years in Fig. 2. We see that bridging and linking capital are closely positively related, as expected, while bonding capital is slightly negatively related with these two indices. This is largely expected. A new finding of this analysis is that bonding social capital is slightly positively related with social vulnerability, while bridging and linking social capital are negatively related to vulnerability. This is worrisome for Japanese municipalities, since vulnerable communities are exactly the kind of community that would benefit from *more* bridging and linking social capital to respond to disasters.

5.2. *Geography of social capital*

These trends raise larger questions. Which communities tend to receive higher or lower index scores, and how do they vary geographically? To further discuss these trends, I visualized the variation in municipal social capital and social vulnerability indices throughout all 1741 Japanese municipalities in Figs. 3 and 4 (Okinawa is not pictured, but it is included in the indices).

In Fig. 3, index scores were binned into quintiles by index, so that

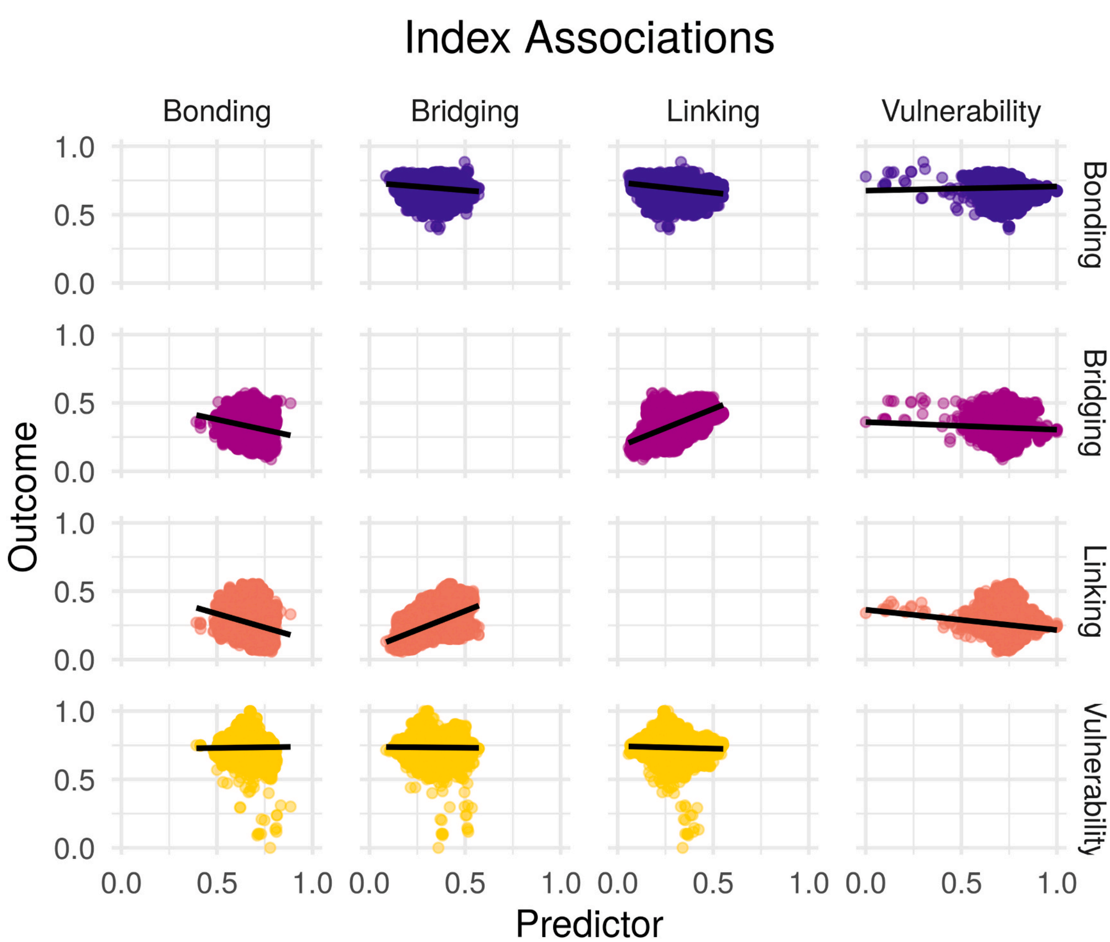

Fig. 2. Index associations.

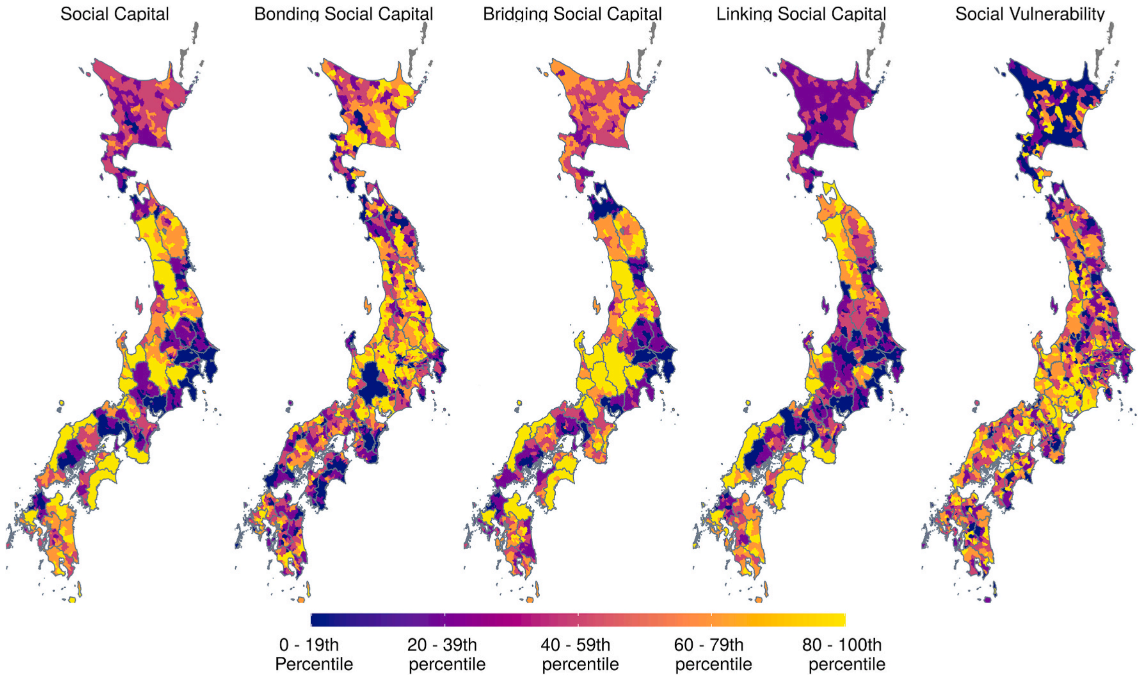

Fig. 3. Community resilience factors in 2017 by quintiles.

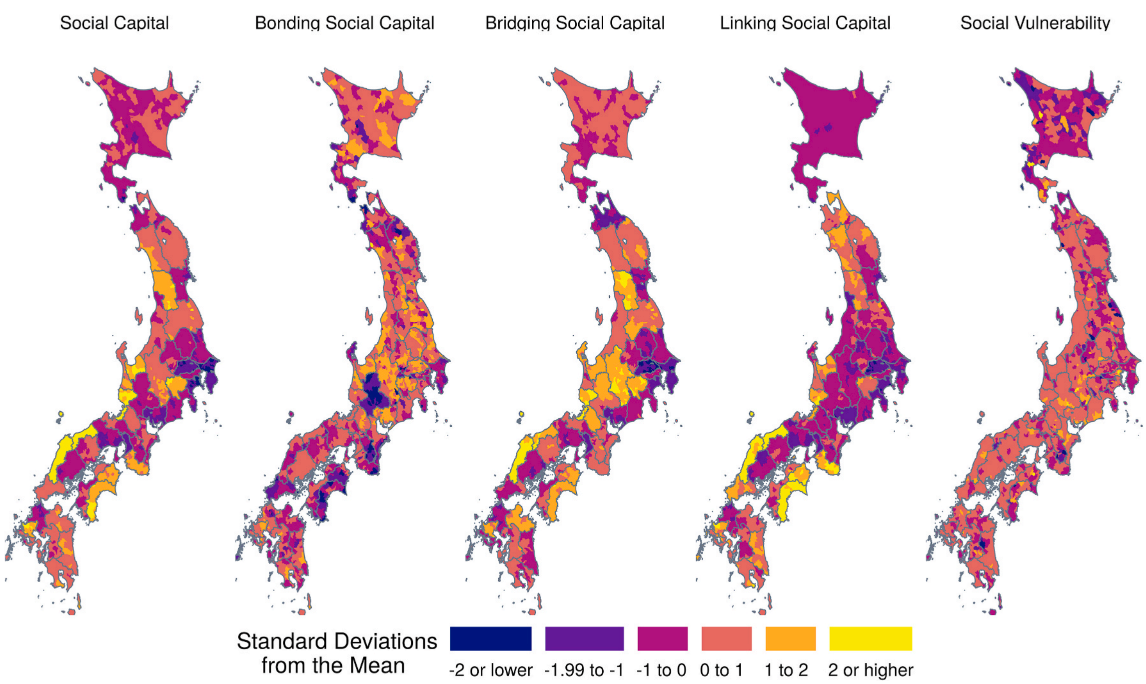

Fig. 4. Community resilience factors in 2017 in standard deviations from the mean.

each map depicts the range of towns with the highest and lowest bonding social capital, bridging linking capital, and so on. Meanwhile, in Fig. 4, index scores were visualized as Z-scores in terms of standard deviations from the mean. This helps us make useful comparisons among towns. First, two broad trends can be observed. Municipalities around the metropolises of Tokyo and Nagoya tend to face higher social vulnerability and higher bonding social capital, comparable with that of depopulating rural towns in Northern Hokkaido, which have surprisingly low social vulnerability. These indicators suggest that urban regions might be less resilient to shocks, and efforts to build greater bridging and linking social ties could help ameliorate the effects of future shocks.

Second, while social capital and vulnerability do cluster regionally, these maps highlight that considerable intra-prefectural variation also occurs. Notably, Hokkaido and Kyushu (the northernmost and southernmost regions of Japan) are home to considerable variation in all five indices. This poses a natural question of why, which future research should certainly explore.

The most socially vulnerable towns in Japan right now are rightfully so Naraha-machi and Katsurao-mura, both located in the Fukushima exclusion zone. Next, however, are Oizumi-machi in Gunma and Kawakami-mura in Nagano. In contrast, the top 5 towns with the highest social capital are all located in Tottori prefecture: Iwami-cho, Yazu-cho, Hiezu-son, Hino-cho, and Kofu-cho, partially due to several of them (Iwami and Yazu) having the highest linking social capital as well. This is good news for Tottori, a depopulating rural region; despite facing decline for several years, it now has extremely high numbers of elected officials, local government workers, and police workers per capita, which increases the number of people citizens can contact about public affairs.

Similarly, rural regions can also gather very high bridging social capital. For example, the following prefectures' towns are nearly entirely ranked in the top quintile of bridging and linking social capital, and 1 or even 2 standard deviations from the mean: Tottori and Shimane in the Chugoku region, Kochi and Tokushima in Shikoku, Nagano, Gifu, and Toyama in Chubu, and Yamagata and Fukushima in Tohoku. These communities (with the exception of Fukushima, which is socioeconomically vulnerable from prior disasters) would be much more capable of weathering crises. However, recent disasters have primarily struck other locales. In 2019, typhoons struck the greater Tokyo metropolitan area, causing much damage to towns in Chiba, which this set of indices suggests is especially vulnerable, seeing moderate-to-high social vulnerability but a dearth of bridging or linking social capital.

5.3. Generalizability and limitations

These indices provide a useful tool for social scientists to use in the context of Japan. This index can be used to compare towns in the same prefecture, in different prefectures, and can also be averaged upwards to the prefectural and regional level. It should not be compared *directly* to the US Social Capital Index or Social Vulnerability Index, because these scores have been collected from different data and their range may differ, but it can be used analogously to test whether the same trends occur in Japan vs. the US or other countries. Finally, like all large data projects, this index suffered from missing data and relied on filling in missing variable-years with the most recently available years. Extensive comparisons across 135 different index combinations showed that mean imputation produced the most valid indices. However, these indices draw from multiple variables, meaning that even with the imputation of some missing data, they still reasonably portray average values for each concept.

6. Conclusion

In summary, this study expanded past methodologies by creating a new Japanese social capital and social vulnerability index over time, creating annual measures for each of Japan's 1741 municipalities from 2000 to 2017. I validated each measure by identifying whether averaging indicators or using principal component analysis on indicators led to indices that produced the same recovery outcomes predicted by the literature. These validation models showed that the averaging indicators is the best method for social capital indices, while principal component analysis produces the better form of the social vulnerability index. Finally, by visualizing the relationships and geographic patterns of social capital and vulnerability, I showed that some key regions (namely Tokyo and Nagano) suffer from high social vulnerability and weak bridging and linking social capital, while other rural regions (eg. Tottori) have strong community resources to draw on in times of crisis.

This study makes three main contributions to the literature. First, while past scholars have relied upon proxies for social capital and vulnerability, such as crime rates for bonding social capital, voter turnout for bridging social capital, or infrequent, aggregated survey measures from the General Social Survey [21,69,80,92], these indices provide a more inclusive representation of these trends by combining multiple indicators through averaging and principal component analysis.

Second, this study directly integrates social capital and social vulnerability literature by highlighting how these two indices can be used together as a diagnostic tool for assessing community resilience. While state policymakers in the US have relied on the Social Vulnerability Index for over a decade to make these inferences [70], this study suggests that these tools work best when analyzed together, echoing recent reviews in the field [64].

Third, this study builds on over two decades of social capital research in Japan by providing a comprehensive index that political scientists, sociologists, and geographers can use to explain changing local level policy outcomes, economic outcomes, and community resilience outcomes since 2000. While many scholars have indicated that local level organizing has major effects on the urban planning, quality of governance, community resilience, and policy changes in Japanese municipalities [12,21,53,56–58,69,77,92–94], these questions can now be examined in-depth, over time, through multiple frames of social capital research.

In the future, this index should especially be applied to examine questions of municipal level variation in resilience outcomes. By pairing this dataset with Japanese census data, scholars can use this index to refine old and new research questions. In particular, this data should be used to test variation in recovery outcomes over time, a topic which in the past was limited by the fact that scholars lacked annual, publicly available measures of social capital. Whether bonding, bridging, or linking social ties affect evacuation, adaptation to climate change, recovery outcomes, infrastructure policies and more can be readily examined. I hope this research can help scholars and policymakers make key interventions to improve communities' resilience to climate change related hazards [71–87].

Data availability

Index data and code are freely available for replication on the Harvard Dataverse, found at the following link: https://doi.org/10.7910/DVN/PBBKBF.

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Declaration of competing interest

The authors have no conflicts of interest to report.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2020.101965.

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