Living in a Ghost Town:
The Geography of Depopulation and Aging

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Abstract

We study how depopulation and aging progress across regions within a country and how this process affects economic welfare across regions and generations. Using spatially disaggregated data from Japan for the last 40 years, we document that youths' out-migration accelerated rural depopulation and aging. This process led to a decline in rural economic activity. Motivated by this evidence, we develop a dynamic life-cycle spatial equilibrium model of migration decisions. We calibrate our model to the historical spatial population changes in Japan and use this model to project future spatial patterns of depopulation and aging. We show that internal migration is crucial for the future spatial patterns of depopulation and aging, affecting aggregate and distributional welfare across regions and generations.

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1 Introduction

It is well known that aging and depopulation (population decline) are among the major challenges for the world this century. By 2050, 26 countries are estimated to reduce their population by more than ten percent (United Nations, 2019). At the same time, 16 percent of the world population is estimated to be over age 65 by 2050, almost doubling from 9 percent in 2019. Academics and policy-makers have cautioned that the declining population size and labor force affect various aspects of our lives, in particular by slowing economic growth and by increasing the burden of economically sustaining the elderly.

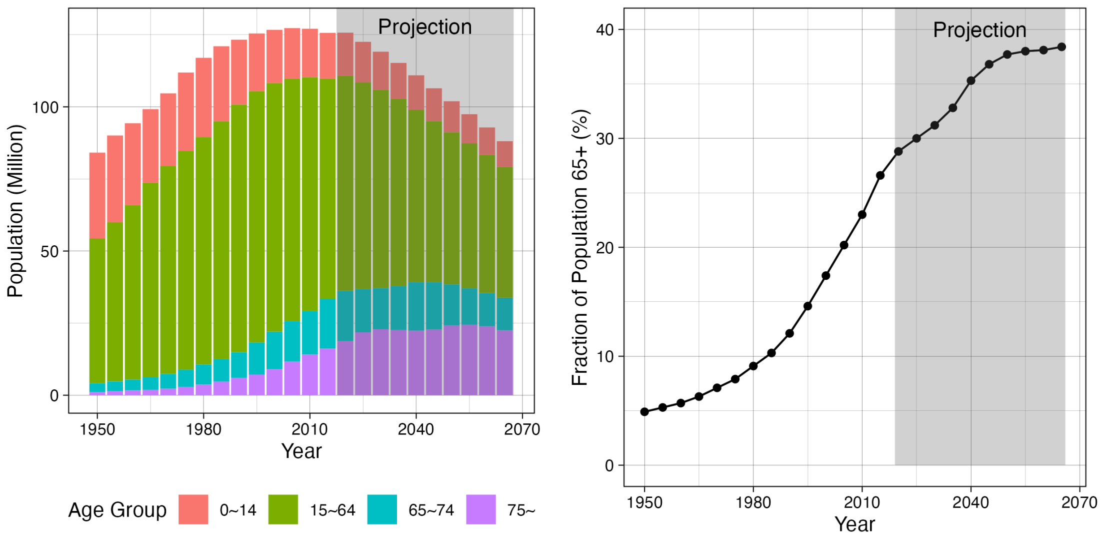
What is less studied is that aging and depopulation mask critical spatial heterogeneity within a country. Anecdotal evidence highlights the strong incumbency of locations losing working-age populations rapidly (i.e., "ghost towns") while some regions pullulate with youth. Since many aspects of our economic activity are influenced by the local economic activity (e.g., labor market, amenities, housing), the differential rates of depopulation and aging may affect regional disparity in economic activity and welfare. Importantly, internal migration may affect the process of regional depopulation and aging, while simultaneously affecting the aggregate welfare and its heterogeneity across regions and generations. If this is the case, policies subsidizing migration to rural areas, as found in Japan and many European countries, may have important aggregate and distributional implications.

Against this background, this paper studies how depopulation and aging progress across regions within a country and how this process affects aggregate welfare, with heterogeneity across regions and generations. We argue that internal migration over the life cycle is critical to understanding these issues. Using spatially disaggregated data from Japan for the last 40 years, we document that youths' out-migration accelerated rural depopulation and aging. This process led to a decline in rural economic activity. Motivated by this evidence, we develop a dynamic life-cycle spatial equilibrium model of migration decisions. We calibrate our model to the historical spatial population changes in Japan and use this model to project future spatial patterns of depopulation and aging. We show that internal migration is crucial for the future spatial patterns of depopulation and aging, affecting aggregate and distributional welfare across regions and generations.

Japan is a natural setting to study these questions. As of 2015, Japan accommodates the world's highest faction of the aged population; 26 percent of the population was over 65 years old in 2015, and it is expected to rise to 37 percent by 2050 (Figure 1). The population has started declining since 2010, and it is expected to shrink by nearly 20 percent relative to

Figure 1: Aggregate Patterns of Depopulation and Aging in Japan

(a) Population Decomposition by Age (b) Fraction of Population above 65 Years Old



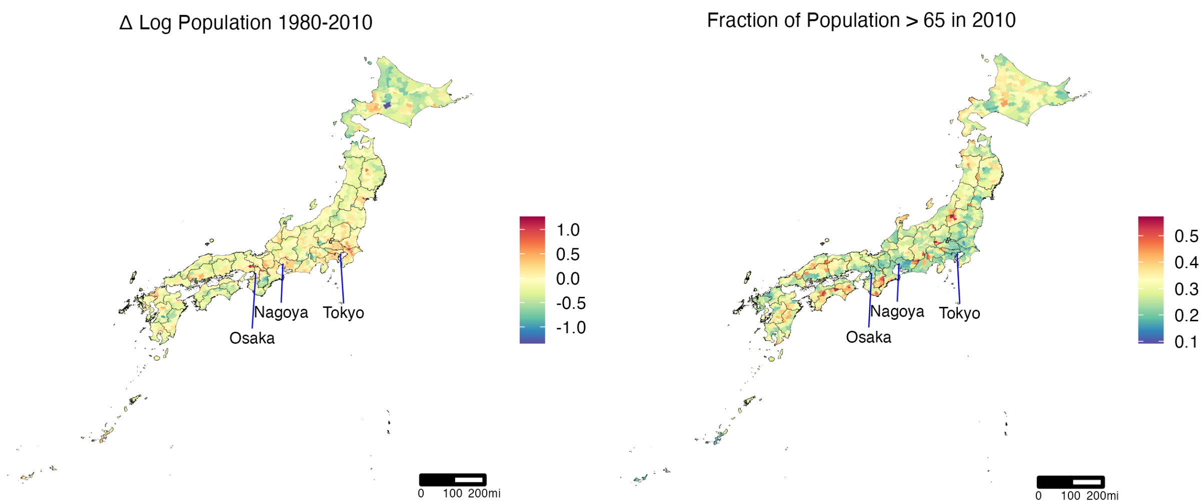
Source: Official Statistics.

2010 by 2050. Increasing life expectancy and falling fertility rates primarily drive this pattern (Figure B.1).[1]

At the same time, there is substantial heterogeneity in depopulation and aging across regions. The left panel of Figure 2 shows the population size changes from 1980 to 2010 across municipalities in Japan (left figure). There is a huge variation in the changes in population size. Some municipalities are doubling their population size over the 30 years, particularly those around major metropolitan areas in Japan, Tokyo, Osaka, and Nagoya. At the same time, some municipalities in rural areas have lost population by more than 100 percent. The right panel of Figure 2 shows the fraction of the population over 65 years old. Similarly, as the population size changes, there is a huge spatial variation. Around major metropolitan areas, the fraction of the elderly is 10-20 percent, significantly lower than the national average of 23 percent. At the same time, in some rural municipalities, over 50 percent of the population is elderly. The apparent heterogeneity of depopulation and aging across municipalities has alarmed policymakers. In a sensational book, "Extinctions of Rural Municipalities (*Chiho Shometsu*)," Hiroya Masuda, then the governor of Iwate prefecture, cautioned that nearly half of municipalities in Japan may disappear by 2040 (*Chiho Shometsu*).

[1] International migration plays a limited role in Japan because there has been limited international out- and in-migration in the past compared to major advanced economies.

Figure 2: Heterogeneity of Depopulation and Aging across Municipalities in Japan



Note: This figure reports the map of Japan at the municipality level. The left figure shows the patterns of the changes in population from 1980 to 2010. The right figure shows the fraction of the population over 65 years old. The black solid border indicates the prefecture boundaries. See Figure B.2 for the density distribution of these variables across municipalities.

The paper is divided into three parts. In the first part, we document spatial patterns of depopulation and aging and how it affects the local economy. We start by documenting the spatial patterns of depopulation and aging using spatially disaggregated data from Japan for the last 40 years. We show that depopulation has progressed more rapidly in rural areas than in urban areas. We also show that this rural depopulation is accelerated by the outmigration of youths on top of natural population changes (birth and death). We also show that this youth's outmigration accelerated rural aging, leaving the elderly in rural areas left behind.

How do these regional depopulation and aging affect the local economy? To answer this question, we also document how regional depopulation and aging affect regional income, various dimensions of amenities (retail, health/medical, elderly service, child/education, environment/transportation), and land prices. To handle the endogeneity of regional depopulation and aging through endogenous migration rates and fertility/mortality rates, we instrument these variables using the predicted depopulation and aging *solely* from the process of birth and death using *national* rates, given the population pyramids in each municipality in 1980 (Shimer, 2001, Maestas et al., 2016, and Acemoglu and Restrepo, 2022). We find that depopulation decreases income, amenities, and land prices. The aging population, proxied by the increase in the fraction of the elderly, decreases income, has mixed effects on different types of amenities (for example, it increases elderly service and decreases retail), and increases land prices. Combining the effects of depopulation and aging for typical "rural" municipalities (bottom 10 percentile of population density in 1980) relative to "urban" municipalities (top 10 percentile), "rural" municipalities tend to face a decrease in income, decrease in amenity for all categories, and decrease in land prices.

To understand the implications of this reduced-form evidence, in the second part of the paper, we develop a dynamic spatial life cycle model of migration decisions. At every period, individuals of different ages make forward-looking decisions to migrate to different locations within a country depending on employment opportunities, amenities, consumption, housing prices, and migration costs. The spatial population distribution, in turn, determines employment opportunities, amenities, consumption, and housing prices. Together, the model allows us to connect the endogenous lifecycle migration decisions with the aggregate dynamics of regional depopulation and aging over time.

Our model provides an intuitive explanation for why the youths' out-migration can be a strong driver of the depopulation and aging of rural areas. The younger population has a stronger incentive to migrate to places with better employment opportunities since the migration pays off over a longer life span. Therefore, a negative local productivity or amenity shock, whether exogenous or arising from agglomeration spillovers, induces the out-migration of youths. On the other hand, the old population is left behind in these regions, i.e., living in a "ghost town." These old generations left behind in depopulated regions may face severe welfare loss because of the increased cost of goods and services and the reduced agglomeration spillovers.

In the third part, we use our model to quantitatively assess the role of internal migration on the spatial patterns of depopulation and aging as well as welfare implications both aggregate and across regions. A key advantage of our model is that it can accommodate many heterogeneous locations with different levels of location fundamentals, including productivity, amenity, and migration costs. We establish a transparent procedure to invert these objects from the observed population distribution and migration patterns. We apply this procedure to calibrate our model to fit the spatially-disaggregated population distribution observed in Japan.

We then use our model to project future spatial patterns of depopulation and aging under the projected fertility and death rates. We demonstrate that abstracting endogenous migration decisions and their effects on local economies substantially biases the projected spatial patterns of demographic changes and welfare. Abstracting internal migration leads to a substantial underestimation of future rural depopulation and aging in rural areas. More importantly, we find that internal migration is a powerful force to offset the welfare decline due to the depopulation at the national level. This is because the population continues to reallocate toward more attractive locations (i.e., Tokyo Metropolitan Area) in the future. This reallocation mitigates the welfare loss from nationwide aging and depopulation. At the same time, residents in depopulated locations face a faster decrease in flow utility because of the lost agglomeration benefit.

The trade-off between aggregate welfare and regional inequality arising from spatial depopulation and aging dynamics is a key challenge for policymakers. In the future, we plan to analyze the implication of place-based policy, such as the ongoing migration subsidies toward rural areas in Japan.

Related Literature Our paper contributes to several related pieces of literature. First, we contribute to the literature on the aggregate and intergenerational effects of depopulation and aging. Following the seminal work by Auerbach and Kotlikoff (1987), this literature has analyzed these effects using the overlapping-generations framework (e.g., De Nardi et al., 1999; Auclert et al., 2021). In particular, this framework has been applied to Japanese contexts to study labor market outcomes and fiscal issues under depopulation and aging (Braun and Joines, 2015; Kitao, 2015; Kitao and Mikoshiba, 2020). In contrast to this literature, this paper highlights the regional incidence of depopulation and aging and its implication for aggregate and distributional welfare.[2]

Second, we contribute to the literature on the life cycle dynamics of an individual's location decisions. This literature has traditionally modeled forward-looking migration decision as a dynamic discrete choice problem and studied its implication for local economic activity (Artuç et al., 2010; Kennan and Walker, 2011; Dix-Carneiro, 2014; Caliendo et al., 2019; Kleinman et al., 2021). More recently, a new set of papers in the quantitative spatial literature has incorporated agents' heterogeneous decisions of migration over their life-cycle (Giannone et al., 2020, Suzuki, 2021, Komissarova, 2022). We contribute to this literature by connecting the life-cycle migration decisions to the aggregate dynamics of depopulation and aging.

[2]Other papers studying the macro-economic implications of aging and depopulation focus on innovation and economic growth (Acemoglu and Restrepo, 2022 and Jones, 2020) and business dynamism (Karahan et al., 2019, Hopenhayn et al., 2021, Engbom, 2019).

More broadly, a growing number of papers have highlighted that people of different age groups make different residential location decisions. Couture and Handbury (2020) and Moreno-Maldonado and Santamaria (2022) document that people at different timing of their life cycles make different location decisions. We contribute to this studies suggesting that depopulation and aging create long-lasting effects on aggregate welfare as well.Gaigné and Thisse (2009) and Takahashi (2022) theoretically analyze how these heterogeneous decisions affect the implication for the nationwide aging under as stylized geography. Our contribution is to analyze these patterns using a quantitative general equilibrium framework capturing realistic geography and migration costs using the Japanese context as a case study.

Lastly, our paper contributes to the literature on demography on local population projection (Smith et al., 2006, 2013). While this literature also highlights the role of internal migration in local population projection, they tend to abstract how migration decisions endogenously change the local economic activity and how it changes the migration decisions in turn. We contribute to this literature by showing that these endogenous migration decisions are crucial for future projection and for the regional and intergenerational welfare implications.

The rest of this paper proceeds in the following way. In Section 2, we describe our main data sources. In Section 3, we document spatial patterns of depopulation and aging in Japan and how it affects the local economy. In section 4, we develop a dynamic life-cycle spatial equilibrium model. In Section 5, we calibrate our model to the population and migration data from Japan. In Section 6, we use our calibrated model to project future spatial patterns of depopulation and aging and discuss its welfare implications.

2 Data Sources

In this section, we describe the geographic unit of Japan and our main data sources. The details and the source of each piece of information are found in Appendix Table A.1.

Geographic Units. Japan is divided into 47 prefectures. Each prefecture is further divided into municipalities. There are 1719 municipalities in Japan as of 2013. The average geographic size of the municipality is around 220 square kilometers. The average population size is 72,000, while there is large heterogeneity in population size, as we document below. The number of municipalities has significantly decreased over the last 20 years due to municipality mergers. To keep the spatial units of our analysis consistent across years and unaffected by the municipality mergers, we use the crosswalk of municipalities across different years in

Japan developed by Kondo (2019) and take the spatial unit at the level of municipalities in 2010.

Population Census. Population censuses in Japan are conducted every 5 years by the Statistics Bureau of the Ministry of Internal Affairs and Communications. The population censuses collect each individual's demographic characteristics (e.g., age, gender) and the current residential location. Furthermore, every 10 years (and every 5 years after 2010), the population censuses also collect information on where each individual resided 5 years ago. We use this information to extract migration flows. Lastly, we use information about employment status by age, gender, and municipality for calibrating our model.

Vital Statistics. Vital statistics are collected annually by the Ministry of Health, Labor, and Welfare. This data reports the number of birth for each prefecture disaggregated by the mothers' age. We construct fertility rates by mothers' age for each prefecture using this information. This data also reports the number of death for each prefecture disaggregated by age and gender, while it is also available at the municipality level since 2000. We construct mortality rates by age and gender for each prefecture using this information.

Projected Fertility and Mortality Rates. We use the projected fertility and mortality rates at the national level from 2015 to 2065 reported by the National Institute of Population and Social Security Research (IPSS) in Japan. We use this information to conduct the future projection using our calibrated model.

Taxable Income. We measure the average income of the residents in each municipality using official data on the tax base for that municipality collected by the Ministry of Internal Affairs.

Economic Census: We use data from the Economic Census on total employment and the number of establishments by municipality and sector.

Basic Survey on Wage Structure. We extract information about wages by gender and age group from the Basic Survey on Wage Structure. It is an annual survey conducted on a random sample of establishments across Japan by the Ministry of Health, Labour, and Welfare. This data is available at the prefecture level. We extract average wages for each prefecture, age group, gender, and occupation. We use this information for calibrating our model.

Land Prices. We measure the changes in land prices using the official posting of land prices of designated plots across Japan posted by the Ministry of Land, Infrastructure, Transport and Tourism. For each plot, the data reports the evaluated land prices based on the characteristics of the plot and the surrounding environment. This data is typically used as a reference for property tax collection and land transactions.

Amenity Index. We collect various proxies for residential amenities. For our purpose, we classify the amenities into five categories: (1) retail (number of retail stores, large retail stores, clothing stores, food and beverage retail stores, restaurants, barber shops and beauty salons); (2) health/medical (number of general hospitals, clinics, medical doctors, nurses); (3) elderly services (number of nursing homes, community centers, senior citizen clubs); (4) child/education (number of daycares, schools, teachers); (5) environment/transportation (road length, paved road length, number of parks, number of police stations). Following Diamond (2016), for each category, we create an index using principal component analysis (PCA). Appendix Table A.2 reports the loading coefficients of each variable within each category.

3 Reduced-Form Facts

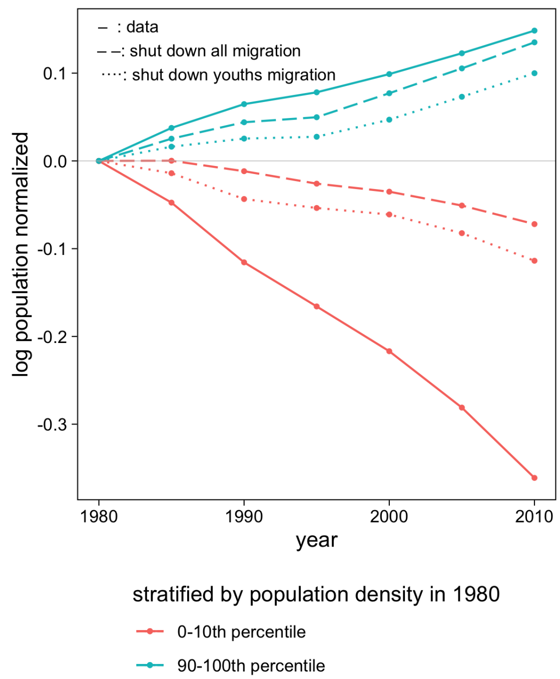
In this section, we document the spatial pattern of depopulation and aging in Japan and how it has affected the local economy.

3.1 How do depopulation and aging progress across regions?

We first document how the spatial pattern of depopulation and aging in Japan has evolved since 1980. Figure 3 shows the growth rates of population size from 1980 to 2010 for the top and bottom 10 percentile municipalities in terms of population density in 1980. Throughout this section, we call the former "urban" and the latter "rural," respectively. Solid lines labeled "data" indicate the population size of these two sets of municipalities normalized by the values in 1980. It is clear that "urban" municipalities have become even denser, and "rural" municipalities have been rapidly losing population.[3]

[3] In Appendix Figure B.3, we show that the change in population size is roughly monotonic across different levels of population density in 1980, except that the relationship is slightly decreasing at the highest-density

Figure 3: Changes in Population Size across Municipalities and Role of Migration



Note: This figure shows the log population size from 1980 to 2010 for the top and bottom 10 percentile municipalities in population density in 1980, normalized by the value in 1980. The solid line labeled "data" reports the values as observed in the population census. The dashed line labeled "shut down all migration" reproduces the hypothetical simulation of shutting down all migration. The dotted line labeled "shut down youths migration" instead plots the hypothetical population size change under the simulation of shutting down youths (age 15-24) migration. See the main text for how we undertake this hypothetical simulation.

How much is this change driven by natural population change (birth and death), and how much is it driven by migration across regions? To answer this question, we compute the hypothetical changes in population size, assuming that there was no migration across municipalities. More specifically, denote the observed distribution of population size of age group a in municipality n in year t by $L_t^n(a)$. The hypothetical population without migration, $L_t^{n*}(a)$, is sequentially constructed from $t = 1980$ as

$$\frac{L_t^{n*}(a)}{L_{t-5}^{n*}(a)} = \frac{L_t^n(a)}{L_{t-5}^n(a)} \times \left(1 + \text{Net-Migration-Rate}_t^n(a)\right), \tag{1}$$

where we start from $L_{1980}^{n*}(a) = L_{1980}^n(a)$, and Net-Migration-Rate$_t^n(a)$ is defined as the net

levels, likely driven by the saturation of population in urban core areas.

out-migrated population from n between $t-5$ and t whose age is a in year t divided by $L_t^n(a)$. Intuitively, the expression recovers how many populations of age a would have been in municipality n if there had been no internal migration in the past 5 years.

The dashed line labeled "shut down all migration" of Figure 3 plots the population size changes in this hypothetical scenario. The results show that the population decline in "rural" municipalities and population increase in "urban" municipalities would have been slower. These patterns indicate that out-migration from "rural" municipalities and in-migration to "urban" municipalities have accelerated rural depopulation and urban concentration. Even in the absence of migration, population size had declined in "rural" municipalities, and it had increased in "urban" municipalities. This is primarily because there was more population under reproductive age in urban areas than in rural areas in 1980. Nonetheless, the contribution of internal migration is more important in explaining this pattern than the natural population change due to birth and death.[4]

We now argue that among migration, youths' migration is particularly relevant for the spatial patterns of depopulation. The dotted line labeled "shut down youths migration" of Figure 3 shows the population size changes when we hypothetically shut down migration for a subset of the population that falls in the 15-24 years old. More specifically, we compute the hypothetical population changes using equation (1) for these age groups while taking the population size of other age groups as observed. We find that, for "rural" areas, shutting down youths' migration would lead to a slightly faster but similar rate of depopulation than when we shut down all migration. This pattern indicates that youths' outmigration explains a large fraction of the depopulation due to migration. For "urban" areas, shutting down youths' migration would lead to slower population growth than when we shut down all migration. This pattern indicates that populations of other age groups on net migrate out from the "urban" areas.[5]

Figure 4 shows the observed net migration rates in "urban" municipalities and "rural" municipalities (top and bottom 10 percentile municipalities by population density in 1980, respectively) are consistent with the patterns explained so far. Panel (a) shows the net out-migration rate for "urban" and "rural" municipalities for three census years (1990, 2000,

[4]There has been limited *international* migration from and to Japan, and it has limited contribution to these processes.

[5]In Appendix Figure B.3, we show that for median municipalities (40-60 percentiles of population density in 1980), shutting down youths' migration would lead to faster population growth than when we shut down all migration, suggesting that population outside age 15-24 tend to migrate out from top municipalities to median municipalities.

2010). Throughout the years, less dense municipalities lost population because of the positive net out-migration, and denser municipalities gained population because of the negative net out-migration. In Panels (b) and (c) of Figure 4, we present the same information disaggregating by end-of-the-period age groups. In the "rural" municipalities in Panel (b), a huge spike is observed in the 15-24 age group. There is a slight drop in the 25-29 age group, likely due to return migration after education. However, this drop is not large enough to offset the surge in the 15-24 age group, and net out-migration rates are relatively flat after these age groups. In "urban" municipalities in Panel (c), net in-migration is primarily driven by the 15-24 age group. In fact, all other age groups exhibit a small but positive net out-migration rate. Overall, these findings reinforce the results in Figure 3 that youths on net migrate out from "rural" municipalities and into "urban" municipalities. The older cohort does not offset these flows.

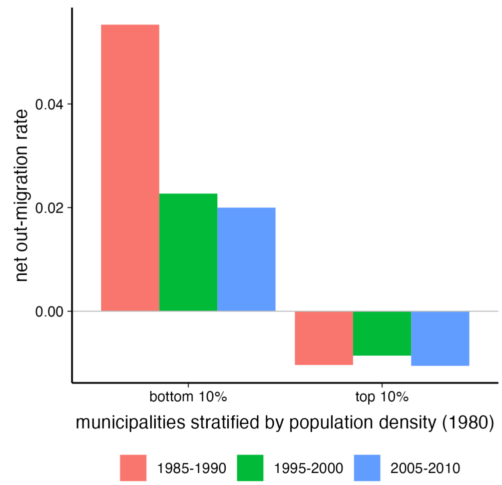
Internal migration affects not only the pattern of depopulation but also regional aging. Figure 5 shows the transition of the fraction of the elderly (over 65 years old) from 1980 to 2010 for "urban" and "rural" municipalities. We also overlay the patterns under the hypothetical scenario of shutting down migration and youths' migration following the same procedure in Figure 3. We find that the fraction of the elderly is consistently higher in "rural" municipalities than "urban" municipalities throughout the period. We also find that the increase of the fraction of the elderly is substantially less when we shut down migration ("shut down all migration"). This is because net out-migration from "rural" municipalities is concentrated among youths (Figure 4), and hence shutting down migration would decrease the fraction of the elderly in the region. Similarly, shutting down the migration of youths only ("shut down youths migration") would lead to a further decline in the fraction of the elderly because this scenario does not shut down the net outmigration of the population outside youths. These findings are consistent with the interpretation that youths' outmigration from "rural" areas is not perfectly offset by the outmigration of older cohorts, leaving elderlies behind in depopulated and aging rural areas.

3.2 How do depopulation and aging affect local economy?

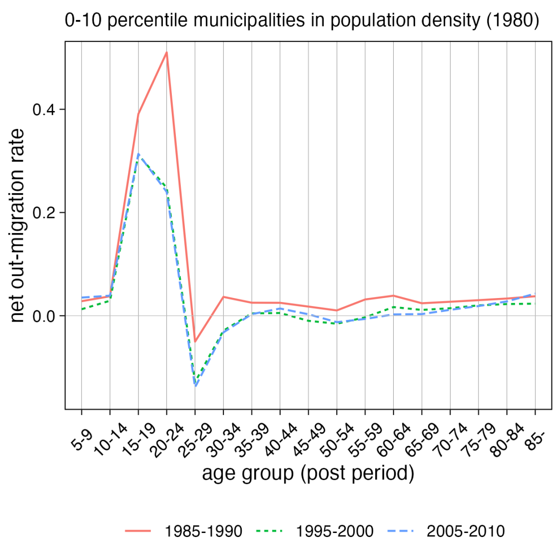
In the previous subsection, we document that there is substantial spatial heterogeneity in the rate of depopulation and aging. In this subsection, we study how they affect the local economy, such as production, amenity, and land prices. In particular, we study how local economic conditions respond to depopulation and aging using the following regression

Figure 4: Net Out-Migration by Location and Age

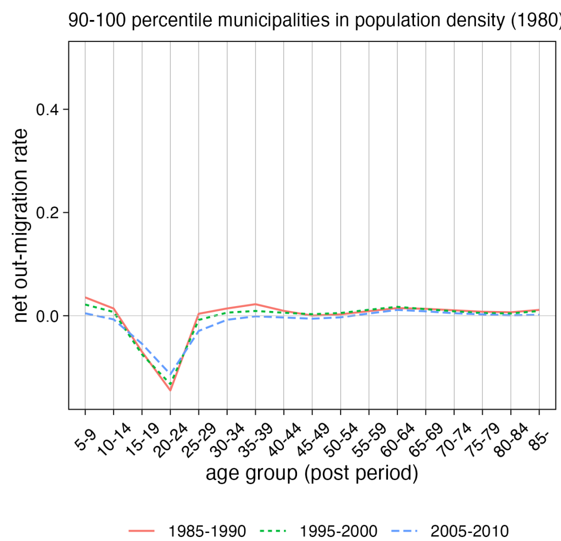
(a) Net Out-Migration Rate



(b) Net Outmigration by Age:
Bottom 10% in Population Density (1980)



(c) Net Outmigration by Age:
Top 10% in Population Density (1980)

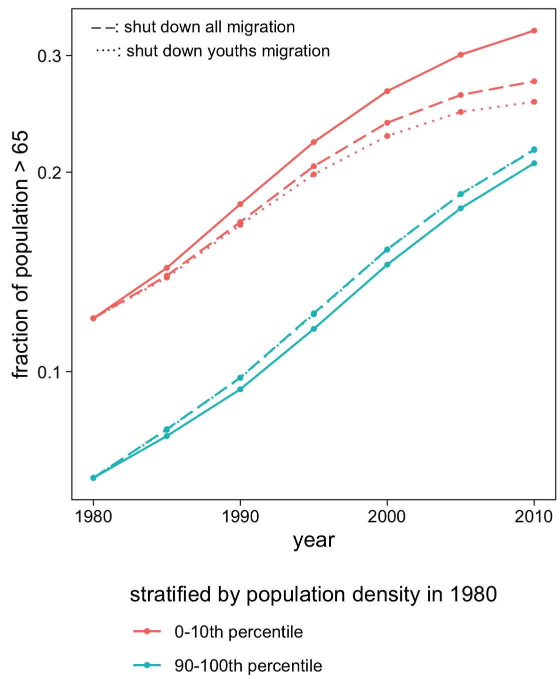


Note: Panel (a) reports the five-year net out-migration rate for the top and bottom 10 percentile municipalities in population density in 1980 for three census years (1990, 2000, 2010). The net out-migration in a municipality is defined by the number of people who have moved out minus those who have moved into the municipality, divided by the population size in the municipality five years before. Panels (b) and (c) report the same patterns by further disaggregating by age groups.

specification:

$$\Delta \log Y_n = \beta_1 \Delta \ln Pop(age \geq 15)_n + \beta_2 \Delta \ln \frac{Pop(age \geq 65)_n}{Pop(age \geq 15)_n} + PrefFE_n + \varepsilon_n, \qquad (2)$$

Figure 5: Decomposition of Aging by Net Out-Migration



Note: This figure shows the fraction of the population over 65 years old from 1980 to 2010 for the top and bottom 10 percentile municipalities in population density in 1980. The solid line shows the transition from the data, the dashed line labeled "shut down all migration" shows the hypothetical simulation of shutting down all migration, and the dotted line labeled "shut down youths migration" shows the hypothetical simulation of shutting down youths (age 15-24) migration. See the main text for how we undertake these hypothetical simulations.

where n indicates the municipality; Δ indicates the long difference between 1980-2010 (or the closest years depending on the availability of outcome variables); and $PrefFE_n$ indicates the prefecture fixed effects. The first dependent variable ($\Delta \ln Pop(age \geq 15)_n)$) proxies the growth rates of population size, and the second dependent variable ($\Delta \ln \frac{Pop(age \geq 65)_n}{Pop(age \geq 15)_n}$) proxies the growth rates of the fraction of the elderly.

A key endogeneity issue of this regression specification is the endogeneity of the growth rates of population size and the fraction of the elderly. For one thing, migration is endogenous to local economic conditions. For example, people migrate out of a region with a decline in productivity or amenity. For another, fertility rates and survival rates may also be endogenous to local economic conditions. To address these concerns, we instrument the observed changes in the population size and the fraction of elderly using the predicted values *solely* from the process of birth and death using their *national* rates given the population pyramids in each municipality in 1980.[6] More specifically, we construct the hypothetical population size of age a in municipality n in year t, $\tilde{L}_t^n(a)$, starting from the observed population size in 1980, $\tilde{L}_{1980}^n(a) = L_{1980}^n(a)$, using the following equation:

$$\tilde{L}_{t+1}^n(a) = \begin{cases} \sum_{a'} \overline{\varkappa}_{t+1}(a')\tilde{L}_{t+1}^n(a') & \text{if } a = 0 \\ \overline{s}_t(a-1)\tilde{L}_t^n(a-1) & \text{if } a > 0 \end{cases}, \tag{3}$$

where $\overline{\varkappa}_t^n(a)$ is the *national* fertility rate by mothers' age a in t and $\overline{s}_t(a)$ is the *national* survival rate of age a in t. We use the national fertility and survival rates to avoid the potential endogeneity that changes in local economic activity are correlated with regional fertility and survival rates. Using the predicted population pyramids in 2010, $\{\tilde{L}_{2010}^n(a)\}$, and the observed population pyramids in 1980, $\{\tilde{L}_{1980}^n(a)\}$, we construct the predicted changes in the changes of population size and the fraction of the elderly. We use these values for instrumental variables (IV) for the first two regressors in equations (2).

Intuitively, these IVs use the following variation. In a region where there is a higher share of newborn and reproductive pop ($age < 39$) in 1980, we would expect that population growth ($\Delta \ln Pop(age \geq 15)_n$) is higher. Similarly, in a region where there is a higher share of middle age ($35 < age < 59$), the fraction of the elderly is expected to be higher ($\Delta \ln \frac{Pop(age \geq 65)_n}{Pop(age \geq 15)_n}$). In Appendix Figure B.4 and B.5, we show that the two IVs have independent variations induced by the different age components of the population pyramids in 1980, as discussed above.

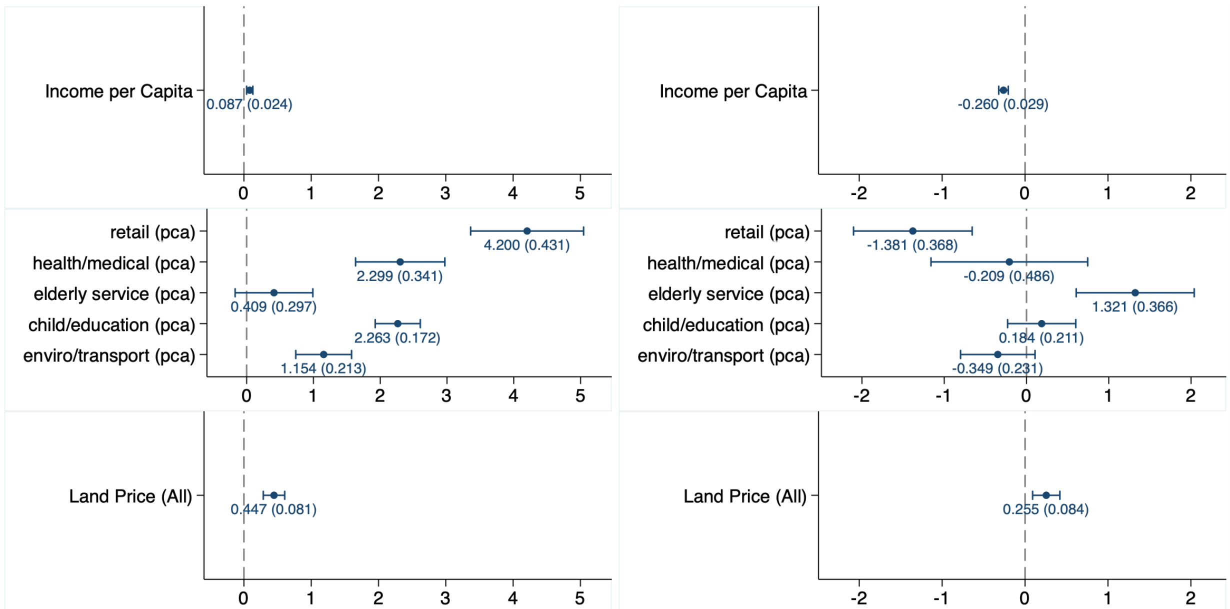
Figure 6 shows the regression coefficients of the IV specification (2). Panel (a) shows the coefficients and the 95-percentile confidence intervals on the log change in population size for each outcome variable indicated in the horizontal axis, and Panel (b) shows those on the log change in the fraction of the elderly. All variables except for amenity proxies in the middle panel are defined as log changes. For amenity proxies in the middle panel, we standardize the growth rates of these proxies to a standard deviation of one.

The top panel reports the impacts on the taxable income per capita. We find that a one percentage point increase in population size increases the income per capita by 0.087 log points. This value aligns with the literature on the agglomeration benefit in wages or productivity (e.g., Melo et al., 2009). At the same time, a one percentage point increase in the fraction of the elderly decreases the income per capita by 0.260 log points. The negative

[6] Previous literature using the lagged population pyramids to construct an instrument for population aging includes Shimer (2001), Maestas et al. (2016), and Acemoglu and Restrepo (2022).

Figure 6: Impacts of Depopulation and Aging on Local Economy

(a) Δ log Population (b) Δ log Fraction of the Elderly



Note: This figure reports the coefficient estimates of equation 2 where each dependent variable is in changes of local economy determinants. The left panel reports the coefficients on Δ log population, and the right panel reports the coefficients on Δ log fraction of the elderly. All variables except for amenity proxies in the middle panel are defined as log changes. For each amenity proxy in the middle panel, we standardize the growth rates of these proxies to a standard deviation of one.

effects of the fraction of the elderly are consistent with the lower employment rates of the older population.

The middle panel reports the impacts on the PCA indices of the five categories of amenities: (1) retail, (2) health/medical, (3) elderly services, (4) child/education, (5) environment/transportation.[7] We standardize the growth rates of these proxies to a standard deviation of one. Our findings are summarized as follows. First, we find substantial heterogeneity in the impacts of population size and the fraction of the elderly across amenity categories. Second, we find that population size has significant and positive effects on all categories of amenities except for "elderly service," which is positive but not significantly different from zero. The heterogeneous relationship between various types of local amenities and age composition is in line with the findings of Komissarova (2022), who shows this relationship using cross-sectional data from the United States. Third, we find that fraction

[7]See Section 2 for how we classify the original variables into these categories and construct the PCA index, and Appendix B.3.2 for the impacts on the original variables within each classification.

of the elderly has significantly negative impacts on "retail," significantly positive effects on "elderly service." The effects on the other amenity proxies are not significantly different from zero.

The last panel reports the impacts on land prices. We find that population size has a significantly positive effect on land prices. We also find that the fraction of the elderly also has positive effects on land prices, suggesting the possibility that there is a higher demand for land from the elderly population than from the younger population.

To facilitate the interpretation of these regression coefficients, we now illustrate how these regression coefficients lead to the differences in the growth rates in income, amenity, and land prices in "rural" municipalities (the bottom 10 percentile of population density in 1980) relative to "urban" municipalities (the top 10 percentile of population density in 1980). As reported in the previous subsection, the population size has declined by 0.4 log points in "rural" municipalities between 1980 and 2010 while that in "urban" municipalities increased by 0.1 log points, leading to 0.5 log points differences in $\Delta \ln Pop(age \geq 15)_n$. Similarly, the fraction of the elderly has increased by 1.04 log points in "rural" municipalities between 1980 and 2010 while that in "urban" municipalities increased by 1.14 log points, leading to -0.1 log points differences in $\Delta \ln Pop(age \geq 65)_n / Pop(age \geq 15)_n$. Therefore, $-\hat{\beta}_1 \times 0.5 + \hat{\beta}_2 \times 0.1$ is the net effects of "rural" areas relative to "urban" areas from the depopulation and aging.

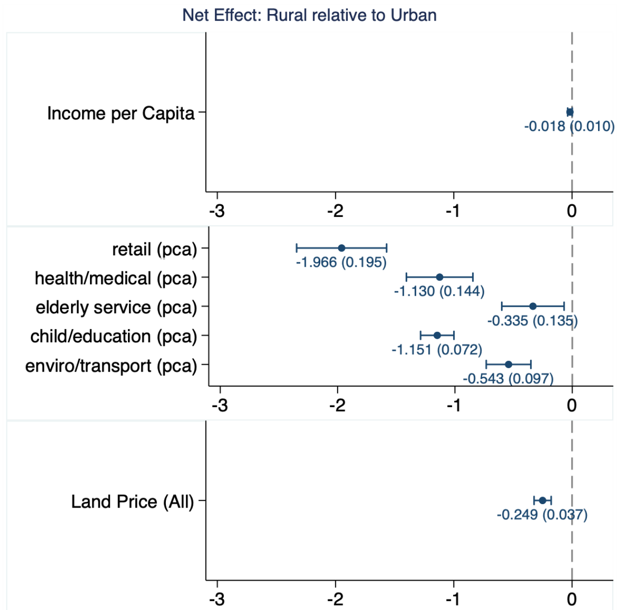
Figure 7 presents the results. On net, we find that average income falls in "rural" municipalities, all categories of amenities fall with varying degrees, and land price falls.

Together, the evidence of this section shows that depopulation and aging have a significant impact on the local economy. Together with the findings in Section 3.1 that outmigration from "rural" areas accelerates depopulation and aging of rural areas, the findings of this subsection may imply an important regional and intergenerational welfare implication. In the next section, we build a spatial dynamic general equilibrium model with lifecycle migration decisions to assess the welfare implications of this phenomenon.

4 Model

In this section, we develop a model of migration decisions over the life cycle. We discuss how the process of birth, death, and migration decisions shape the aggregate spatial dynamics of depopulation and aging.

Figure 7: Predicted Net Impacts of Depopulation and Aging on Rural Economies



Note: This figure reports the predicted differential growth rates in each variable in "rural" municipalities (the bottom 10 percentile of population density in 1980) relative to "urban" municipalities (the top 10 percentile of population density in 1980) based on the estimates of the regression (2). See the text for how we compute these values.

4.1 Basic Setting and Timing

We consider an economy partitioned by a finite number of locations, denoted by $i \in N$. Time is discrete and denoted by $t = 0, 1, 2, \ldots$. In each period t, measure $L^i_t(a)$ of age $a \in 0, 1, \ldots, \bar{a}$ population reside in location i. We describe below how $\{L^i_t(a)\}$ evolve across time through migration decisions and natural population change (the process of population births and deaths).

Within each period t, four events occur in the following order:

1. New agents are born.
2. Agents engage in production and consumption.
3. Agents make migration decisions.
4. Agents die stochastically.

4.2 Population Birth and Death

At the beginning of each period t, agents of age a in location n give birth to age 0 agents at fertility rate $\varkappa_t^n(a)$. The measure of the youngest age group in the location is

$$L_t^n(0) = \sum_a \varkappa_t^n(a) L_t^n(a). \tag{4}$$

At the end of each period t, agents of age a in location n dies at an exogenous probability $1 - s_t^n(a)$, which can flexibly depend on t, location n, and age a. If the agent survives with probability $s_t^n(a)$, she advances her age from a to $a + 1$ when she enters into period $t + 1$ as long as $a < \bar{a}$. To avoid that agents become infinitely old, we assume that agents of age $a = \bar{a}$ remains at age $\bar{a}$ if she survives.

If there is no migration, this process of birth and death is the only source of population changes in this economy. Therefore, the law of motion of population size $\{L_t^i(a)\}$ without migration is given by:

$$L_{t+1}^n(a) = \begin{cases} \sum_{a'} \varkappa_{t+1}^n(a') L_{t+1}^n(a') & \text{if } a = 0 \\ s_t^n(a-1) L_t^n(a-1) & \text{if } 0 < a < \bar{a} \\ s_t^n(\bar{a}-1) L_t^n(\bar{a}-1) + s_t^n(\bar{a}) L_t^n(\bar{a}) & \text{if } a = \bar{a} \end{cases}, \tag{5}$$

4.3 Consumption Decisions

In each period, agents in location n incurs utility from final goods consumption, housing, and residential amenity:

$$u_t^n(a) = \begin{cases} (1-\theta) \ln c_t^n(a) + \theta \ln h_t^n(a) + \ln \chi_t^n(a) & \text{if } a \geq \underline{a} \\ \ln \chi_t^n(a) & \text{if } a < \underline{a}. \end{cases} \tag{6}$$

where $c_t^n(a)$ is consumption of final goods, $h_t^n(a)$ is housing consumption, and $\chi_t^n(a)$ proxies amenity value of location n for age group a at period t. The amenity value $\chi_t^n(a)$ is shaped by the exogenous feature of the location (e.g., access to the ocean, river, forests) as well as endogenously depending on the local population distribution, as we describe further below.

Only individuals with age above the legal working age $\underline{a}(< \bar{a})$ engage in production and earn labor income. We assume that agents do not have saving technology, and hence they spend all the income for the composite of the final good consumption and housing in every period: $w_t^n(a) = c_t^n(a) + R_t^n h_t^n(a)$ for $a \geq \underline{a}$. We assume that final goods can be freely traded and hence normalize their price as one as numeraire. Agents below the legal working age engage in home production and do not consume final goods or housing. Thus, their flow utility is summarized by the amenity value $\ln \chi_t^n(a)$.

4.4 Location Choices over the Life Cycle

At the end of each period t, and before the realization of the death shock, individuals in location n make forward-looking migration decisions on whether to migrate to a different region or stay in the current location. These decisions are based on the expected discounted sum of utility at the destination, bilateral migration costs $\tau_t^{n\ell}(a)$, and the idiosyncratic preference for moving to a particular location $\epsilon_t^{\ell}(a)$. We assume that migration costs can flexibly depend on the origin, destination, time and age groups. Denoting the expected value function of agents of age a in period t in location ℓ by $V_t^{\ell}(a)$, an agent of age a in location n in period t chooses to migrate i if

$$i = \arg\max_{\ell} s_t^{\ell}(a)\beta V_{t+1}^{\ell}(a+1) - \tau_t^{n\ell}(a) + \nu\varepsilon_t^{\ell}(a), \tag{7}$$

where β is a discount factor and ν determines the variance of the idiosyncratic taste shock ε. Recall that $s_t^{\ell}(a)$ is the survival rate and depends on the migration destination an agent moves to.

Assuming that this taste shock is drawn from the Type-I extreme value distribution with mean zero, we can derive the migration share of agents with age group a moving from n to market i as

$$\mu_t^{ni}(a) = \frac{\exp\left[s_t^{i}(a)\beta V_{t+1}^{i}(a+1) - \tau_t^{ni}(a)\right]^{1/\nu}}{\sum_{\ell}^{N} \exp\left[s_t^{\ell}(a)\beta V_{t+1}^{\ell}(a+1) - \tau^{n\ell}(a)\right]^{1/\nu}}, \tag{8}$$

and the expected value of market n for agents with age group a as

$$V_t^{n}(a) = u_t^{n}(a) + \nu \log \sum_{\ell}^{N} \exp\left[s_t^{\ell}(a)\beta V_{t+1}^{\ell}(a+1) - \tau_t^{n\ell}(a)\right]^{1/\nu}, \tag{9}$$

where $u_t^n(a)$ is the flow utility described above.

4.5 Transition of Population Size by Age and Region

Combining the migration decisions and the process of population births and deaths, the law of motion for the population size $\{L_t^n(a)\}$ with migration is given as follows:

$$L_{t+1}^n(a) = \begin{cases} \sum_{a'} \varkappa_{t+1}^n(a') L_{t+1}^n(a') & \text{if } a = 0 \\ \sum_\ell s_t^\ell(a-1)\mu_t^{\ell n}(a-1)L_t^\ell(a-1) & \text{if } 0 < a < \bar{a} \\ \sum_\ell s_t^\ell(\bar{a}-1)\mu_t^{\ell n}(\bar{a}-1)L_t^\ell(\bar{a}-1) + \sum_\ell s_t^\ell(\bar{a})\mu_t^{\ell n}(\bar{a})L_t^\ell(\bar{a}) & \text{if } a = \bar{a} \end{cases}. \tag{10}$$

This accounting relationship is called the "demographic balancing equation" in the demography literature, and it is a building block to the local population projection (Smith et al., 2013). The key distinction between our model and the traditional "demographic balancing equation" is that we specify how migration flows $\mu_t^{\ell n}(a)$ are endogenously determined in the equilibrium depending on wages, rents, and migration costs. As we show below, this distinction makes a substantial difference in the future population projection.

4.6 Production and Wages

In each location, there are perfectly competitive producers that use labor as inputs and produce final goods. We assume that labor is perfectly substitutable across different age groups. To incorporate the heterogeneity of productivity across locations, we assume that the efficiency unit of labor supplied by a worker of age a is given by $\varphi_t^n(a)$. Together with the assumption of perfect competition in the labor market, the labor compensation per headcount of an agent of age a in location n at period t is given by

$$w_t^n(a) = \varphi_t^n(a), \quad a \le \underline{a}. \tag{11}$$

We allow the total working population has an agglomeration spillover effect on labor efficiency.

$$\varphi_t^n(a) = \tilde{\varphi}_t^n(a) \left(\sum_a L_t^n(a) \right)^\gamma, \tag{12}$$

where $\tilde{\varphi}_t^n(a)$ is exogenous productivity and the exponent γ represents the elasticity of agglomeration production spillovers.

4.7 Housing and Amenity

We model the supply of housing H_t^n as a convex function of its price. The higher the price of housing, the higher the supply.

$$H_t^n = \tilde{H}_t^n (R_t^n)^\mu, \tag{13}$$

where $\tilde{H}_t^n$ is the exogenous housing supply shifter and R_t^n is the rental rate of houses in location j at time t. The exponent μ represents the elasticity of housing. This equation mimics the housing sector following Ganong and Shoag (2017). The idea behind this expression is that regulations affect the elasticity of supply as a direct cost shock. Local housing demand follows from the agent problem, and local market clearing implies the housing rent:

$$R_t^n = (\tilde{H}_t^n)^{-1} \left(\sum_{a \geq \underline{a}} \theta w_t^n(a) L_t^n(a) \right)^{\frac{1}{1+\mu}}. \tag{14}$$

As in labor efficiency, we consider an agglomeration amenity spillover (or congestion) effect on the amenity specified as follows.

$$\chi_t^n(a) = \tilde{\chi}_t^n(a) \times \begin{cases} \left(\sum_a L_t^n(a)\right)^{\zeta^{S,Y}} \left(\frac{\sum_{a \geq a^*} L_t^n(a)}{\sum_a L_t^n(a)} \right)^{\zeta^{C,Y}} & \text{if } a < a^* \\ \left(\sum_a L_t^n(a)\right)^{\zeta^{S,O}} \left(\frac{\sum_{a \geq a^*} L_t^n(a)}{\sum_a L_t^n(a)} \right)^{\zeta^{C,O}} & \text{if } a \geq a^* \end{cases} \tag{15}$$

where $\tilde{\chi}_t^n(a)$ is exogenous amenity. a^* indicates the age threshold above which we call the elderly (set at 65 years old in our application). $\zeta^{S,Y}$ and $\zeta^{S,O}$ indicate the amenity externality from the population size for non-elderly and elderly, respectively (superscript S denotes scale effect). $\zeta^{C,Y}$ and $\zeta^{C,O}$ indicates the amenity externality from the fraction of the elderly for the non-elderly and the elderly, respectively (superscript C denotes composition effect). We allow the heterogeneous effects of scale and composition effects across different age groups to capture the heterogeneous responses of depopulation of aging on local amenity as documented in Section 3.2.

4.8 Equilibrium

Given a sequence of exogenous components of productivities $\{\tilde{\varphi}_t^n(a)\}$ and amenities $\{\tilde{\chi}_t^n(a)\}$, migration costs $\{\tau_t^{ni}(a)\}$, fertility rates $\{\varkappa_t^n(a)\}$, survival rates $\{s_t^n(a)\}$, the equilibrium is given by the transition of population $\{L_t^n(a)\}$, wages $\{w_t^n(a)\}$, rents $\{R_t^n\}$, and migration flows $\{\mu_t^{ni}(a)\}$.

5 Calibration

In this section, we calibrate our model using population and migration data from Japan and assess the model fit. With the calibrated parameters in hand, we proceed by inverting the fundamentals. Notice that due to the structure of our model, we cannot apply the dynamic-hat-algebra developed by Caliendo et al. (2019). One of our contribution is, indeed, to develop an alternative inversion method that works also for models with time-varying survival rates as well as fundamentals.

We use 1990 as the initial year ($t = 0$) of the economy, and the frequency of the model is five years. Accordingly, we use 5-year age groups and have 70 or older as the oldest age group ($\bar{a} = 14$). The legal working age is 15 in Japan, which corresponds to $\underline{a} = 3$. The locations are the 47 prefectures of the country.

5.1 Structural Parameters

Table 1 reports in details the calibrated parameters and their sources. Fertility rates $\{\varkappa_t^n(a)\}$ and survival rates $\{s_t^n(a)\}$ before 2015 are calibrated using the births and deaths from the Vital Statistics and the population from the Census data. After 2015, we use the projected fertility and mortality rates by the National Institute of Population and Social Security Research. In order to have a steady state in the long-run, we assume that each location has a replacement level fertility rate starting in period $t = 200$, 1000 years after the initial period.

For other structural parameters, we set ν to 0.3. We follow the housing literature and set the housing supply elasticity to the inverse of 3, close to the estimate for the US. β is set to .97.

We set the scale elasticity of productivity spillover to $\gamma = 0.05$, in line with the estimates in the literature (e.g., Melo et al., 2009) and the estimates of the impacts of population size on taxable income in Section 3.2. We set the scale elasticity of amenity spillover for both non-elderly and elderly to be $\zeta^{S,Y} = \zeta^{S,O} = 0.05$ and the composition elasticity to be $\zeta^{C,Y} = \zeta^{C,O} = 0$.[8]

[8] In the future, we plan to estimate these elasticities using the inverted fundamentals and using the same identification strategy in Section 3.2.

Table 1: Calibrated Parameters and Baseline Variables

Parameters	Description	Values / Sources
ν	shape parameter for migration preference shocks	0.4
β	discount factor	0.97^5
θ	consumption expenditure share of housing	0.33
μ	labor share in housing construction	0.9
$\{s_t^n(a)\}$	survival rates by age and year	official statistics (past and projection)
$\{\varkappa_t^n(a)\}$	fertility rates by age, year, locations	official statistics (past and projection)
T_t	pension payment per elderly population	aggregate pension payment = 110% of elderly labor income
κ_t	income tax rate	set to finance pension payment
$f^{\varphi}(\{L_t^n(\cdot)\})$	productivity spillover function	Section **??**
$f^{\chi}(a, \{L_t^n(\cdot)\})$	amenity spillover function	Section **??**

5.2 Inversion of Fundamentals

As previously mentioned, due to the time-varying survival rates, we cannot apply the dynamic-hat-algebra method of Caliendo et al. (2019). However, calibrating our model under realistic geography is crucial for an accurate future projection of the spatial patterns of depopulation and aging as we demonstrate in the next section. Thus, we develop an alternative method and invert fundamentals across locations, age groups and over time in three steps. First, we invert the exogenous components of productivities $\{\tilde{\varphi}_t^n(a)\}$. Then, we invert bilateral migration costs $\{\tau_t^{ni}(a)\}$ and trade costs $\{\omega_t^{ni}(a)\}$ using our model structure. Lastly, using the model structure, the inverted productivities, trade costs and migration costs, we invert the exogenous components of amenities $\{\tilde{\varphi}_t^n(a)\}$.

5.2.1 Productivity $\{\tilde{\varphi}_t^n(a)\}$

We calibrate the labor productivity using the labor compensation and the employment rate for each age group, location and time, as follows:

$$\varphi_t^n(a) = \text{employment rate}_t^n(a) \times \text{annual labor compensation}_t^n(a). \tag{16}$$

Using the calibrated labor productivity and equation (12), we invert the exogenous component of the productivity.

$$\tilde{\varphi}_t^n(a) = \varphi_t^n(a) \left(\sum_a L_t^n(a) \right)^{-\gamma}. \tag{17}$$

5.2.2 Migration Costs $\{\tau_t^{ni}(a)\}$

We invert the bilateral migration costs using bilateral migration data. To do so, we assume that migration costs are symmetric (i.e., $\tau_t^{ni}(a) = \tau_t^{in}(a)$). By normalizing that the bilateral migration costs within locations are zero (i.e., $\tau_t^{nn}(a) = 0$), we can invert migration costs using the following expression, similarly as Head and Ries (2001) in the context of international trade.

$$\tau_t^{ni}(a) = \ln \left(\frac{\mu_t^{ni}(a)\mu_t^{in}(a)}{\mu_t^{nn}(a)\mu_t^{ii}(a)} \right)^{-\frac{\nu}{2}}. \tag{18}$$

5.2.3 Amenity $\{\tilde{\varphi}_t^n(a)\}$

First, we invert the expected value function $V_t^n(a)$ using the population data and inverted bilateral migration cots. For each age group and each period, the value function can be uniquely inverted up to a normalization (see Redding and Rossi-Hansberg (2017)).

$$L_{t+1}^i(a+1) = s_t^i(a) \sum_n L_t^n(a) \frac{\exp\left[s_t^i(a)\beta V_{t+1}^i(a+1) - \tau_t^{ni}(a)\right]^{1/\nu}}{\sum_\ell^N \exp\left[s_t^\ell(a)\beta V_{t+1}^\ell(a+1) - \tau^{n\ell}(a)\right]^{1/\nu}}. \tag{19}$$

Then, we can invert the flow utility using the inverted value function and an equation that combines the expression for value function (9) with the migration flows (8).

$$u_t^n(a) = V_t^n(a) - s_t^n(a)\beta V_{t+1}^n(a+1) + \nu \ln \mu_t^{nn}(a). \tag{20}$$

Recall from equation (6) that inverted utility flow consists of final goods consumption, housing consumption, and amenity. Using the property of the Cobb-Douglas utility function and housing price in equation (14), we derive the following equation and invert amenity:

$$\ln \chi_t^n(a) = u_t^n(a) - \ln w_t^n(a) + \theta \ln \left(\sum_{a \geq \underline{a}} \theta w_t^n(a) L_t^n(a) \right)^{\frac{1}{1+\mu}} + \mathcal{H}_t^n, \tag{21}$$

where $\mathcal{H}_t^n$ summarizes the terms for housing supply shifter $\tilde{H}_t^n$ and housing expenditure share θ. Note that we cannot separately identify $\ln \chi_t^n(a)$ and $\mathcal{H}_t^n$. Thus, we assume that $\mathcal{H}_t^n = 0$ without loss of generality.

Lastly, we invert the exogenous component using the inverted amenity and equation (15) as follows.

$$\tilde{\chi}_t^n(a) = \chi_t^n(a) \begin{cases} \left(\sum_a L_t^n(a)\right)^{-\zeta^{S,Y}} \left(\frac{\sum_{a \geq a^*} L_t^n(a)}{\sum_a L_t^n(a)}\right)^{-\zeta^{C,Y}} & \text{if } a < a^* \\ \left(\sum_a L_t^n(a)\right)^{-\zeta^{S,O}} \left(\frac{\sum_{a \geq a^*} L_t^n(a)}{\sum_a L_t^n(a)}\right)^{-\zeta^{C,O}} & \text{if } a \geq a^*. \end{cases} \tag{22}$$

6 Future Projections and Welfare

In this section, we use our calibrated model to simulate the future projection of depopulation and aging across Japanese prefectures. To do so, we use our calibrated model to simulate the future evolution of spatial population dynamics. For this simulation, we use the inverted fundamentals up to 2015 and assume that they stay constant afterward. To highlight the role of endogenous migration, we also undertake the same simulation using the special case of our model where we shut down migration ($\tau_t^{ni} \to \infty$ for $i \neq n$).

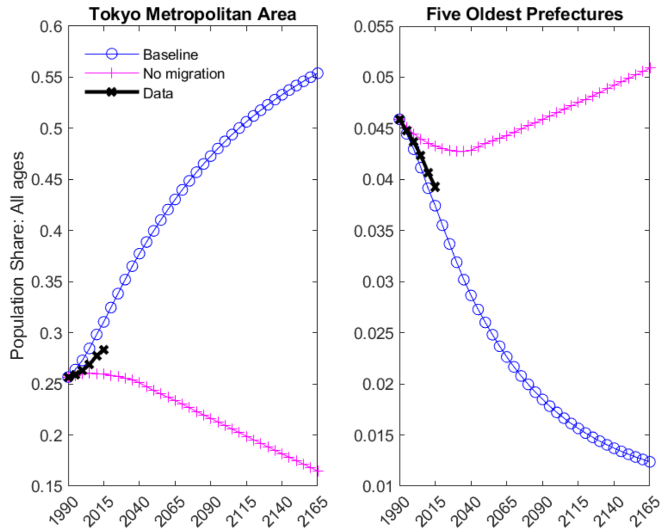
6.1 Projected Pattern of Depopulation and Aging

Figure 8 shows the predicted evolution of population in the Tokyo Metropolitan Area (Tokyo, Kanagawa, Chiba, Saitama) and the five prefectures with the highest average age in 1990 (Shimane, Kochi, Akita, Yamaguchi, Yamagata), respectively. Our baseline model predicts that population share increases in Tokyo Metropolitan Area and decreases in the oldest prefectures for over 100 years in the future. On the other hand, when we shut down migration, the population share instead decreases in Tokyo Metropolitan Area and increases in the oldest prefectures.

Figure 9 shows the future projection of the fraction of the elderly (over 65 years old). In our baseline model, we find that the share of the elderly increases in both regions but that of the Tokyo Metropolitan Area remains lower than the five oldest prefectures. On the other hand, when we shut down migration, the fraction of the elderly will be higher in Tokyo Metropolitan Area in the long run. This is because the fertility rate is lower in Tokyo Metropolitan Area.

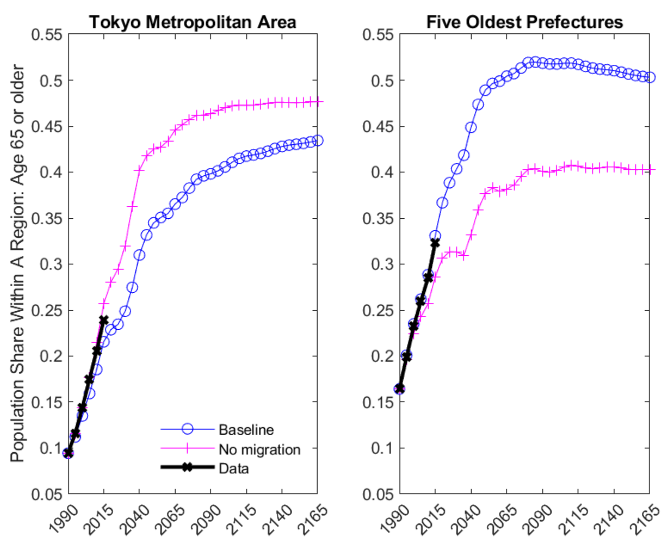
These patterns suggest that migration is key to understand not only the historical patterns of depopulation and aging (as documented in Section 3.1) but also the future spatial patterns of depopulation and aging.

Figure 8: Future Projection: Population Share across Regions



Note: This figure reports the simulation results on the population size in Tokyo Metropolitan Area and the five oldest prefectures.

Figure 9: Future Projection: Population Share of Seniors within a Region



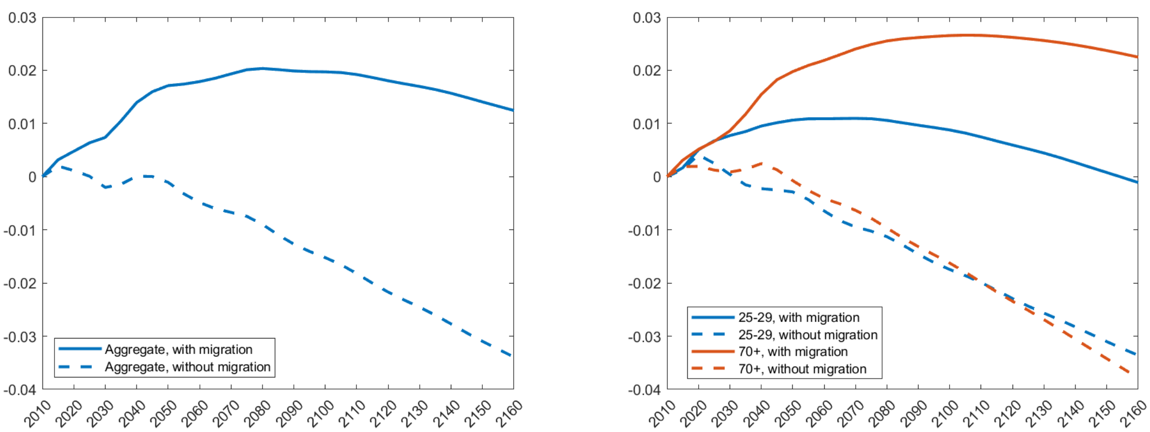
Note: This figure reports the simulation results on the fraction of the elderly in Tokyo Metropolitan Area and the five oldest prefectures.

6.2 Welfare Implications of Aging and Depopulation

We now discuss the welfare implications of aging and depopulation and how internal migration affects this pattern. In Panel (a) of Figure 10, we report the weighted average of the amenity-adjusted consumption-equivalent flow utility (equation 6) across all regions and age groups for each year. We normalize the values at 2010 to emphasize the change over time. In our baseline model (labeled as "with migration"), we find that the flow utility increases until 2080 and then falls. On the other hand, when we shut down migration (labeled as "without migration"), the flow utility continues to fall. This difference arises because migration allows people to reallocate toward locations that offer higher utility (e.g., Tokyo Metropolitan Area).

Figure 10: Flow Utility Over Time, Averaged Across Regions

(a) Aggregate (b) By Age



Note: This figure reports the weighted average of the amenity-adjusted consumption-equivalent flow utility (equation 6) across all regions and age groups for each year. The left panel shows the weighted average across all regions and age groups. The right panel shows the weighted average across all regions for each age group specified in the legend. The solid lines reflect the baseline model and the dotted lines the model without migration.

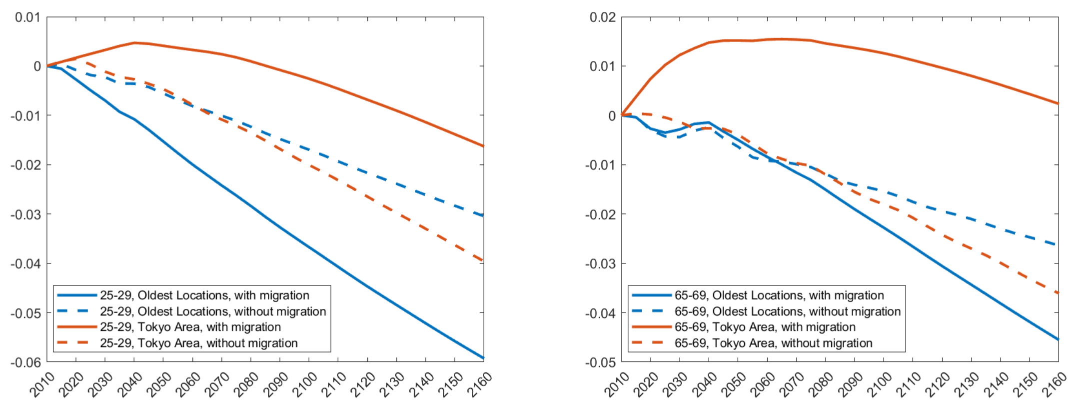
In Panel (b), we report the weighted average of the flow utility across regions and time, separately for youths (25-29 years old) and seniors (over 70 years old). We find that the flow utility increases more for seniors in the presence of migration. This is primarily because migration allows people to optimally reallocate to desirable places during their life cycle. Consistent with this interpretation, when we shut down migration, we find similar patterns of decline for both age groups.

This analysis, however, masks a substantial regional heterogeneity in flow utility. In Figure

11, we report the amenity-adjusted consumption-equivalent flow utility (equation 6) in Tokyo Metropolitan Area and the five oldest prefectures separately for young (in panel a) and seniors (in panel b). In our baseline model (labeled "with migration"), we find that the flow utility increases for Tokyo Metropolitan Area for both age groups over 50 years of the horizon, while those for the oldest prefectures decrease. This is because future population concentration in Tokyo Metropolitan Area makes these regions more attractive through agglomeration spillover in productivity and amenity. Therefore, the regional gap in flow utility continues to widen over time. When we shut down migration (labeled "without migration"), the flow utility decreases at a relatively similar rate.

Figure 11: Flow Utility Over Time, by Regions

(a) Young (b) Seniors



Note: This figure reports the amenity-adjusted consumption-equivalent flow utility (equation 6) in Tokyo Metropolitan Area and the five oldest prefectures separately for young (in panel a) and seniors (in panel b). The solid lines reflect the baseline model and the dotted lines the model without migration.

Overall, these results suggest that migration across regions plays a key role in the welfare implications of aging and depopulation. In the presence of migration, the population (in particular senior citizens) continues to reallocate toward more attractive locations (i.e., Tokyo Metropolitan Area) in the future. This reallocation mitigates the welfare loss from nationwide aging and depopulation. At the same time, residents in depopulated locations face a faster decrease in flow utility because of the lost agglomeration benefit.

The trade-off between aggregate welfare and regional inequality arising from spatial depopulation and aging dynamics is a key challenge for policymakers. In the future, we plan to analyze the implication of place-based policy, such as the ongoing migration subsidies toward rural areas in Japan.

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Online Appendix for "Living in a Ghost Town: The Geography of Depopulation and Aging"

November 2022

A Data Sources

Table A.1: Data Sources

Category	Variables	Spatial Unit	Statistics Name	Source
(A) Population	Population by Age, Gender, and Residence 5 Yeas Ago	Municipality	Population Census	Ministry of Internal Affairs
	Fertility Rates by Mothers' Age	Prefecture	Vital Statistics	Ministry of Health, Labour and Welfare
	Death Rates by Age and Gender	Prefecture	Vital Statistics	Ministry of Health, Labour and Welfare
	Projected Fertility and Mortality Rates	National		Institute of Population and Social Security Research
(B) Income / Employment	Taxable Income	Municipality	Tax Statistics	Ministry of Internal Affairs
	Number Of Workers by Sector	Municipality	Economic Census	Ministry of Internal Affairs
	Number Of Establishments by Sector	Municipality	Economic Census	Ministry of Internal Affairs
	Wage by Age, Gender, Sector, Occupation	Prefecture	Basic Survey on Wage Structure	Ministry of Health, Labour and Welfare
(C) Housing / Land	Total Number Of Residences	Municipality	Housing and Land Survey	Ministry of Internal Affairs
	Posted Land Price	Municipality	Posted Land Price Statistics	Ministry of Land, Infrastructure, Transport and Tourism
(D) Amenity				
Retail	Number Of Retail Stores	Municipality	Economic Census	Ministry of Internal Affairs
	Number Of Large Retail Stores	Municipality	Economic Census	Ministry of Internal Affairs
	Number of Clothing Stores	Municipality	Economic Census	Ministry of Internal Affairs
	Number of Food and Beverage Retail Stores	Municipality	Economic Census	Ministry of Internal Affairs
	Number Of Restaurants	Municipality	Economic Census	Ministry of Internal Affairs
	Number Of Barber Shops And Beauty Parlors	Municipality	Report on Public Health Administration and Services	Ministry of Health, Labour and Welfare
Public Service	Number Of Libraries	Municipality	Prefecture Statistics	Prefecture Office
	Number Of Post Office	Municipality	Post Office Statistics	Post Office
	Road Length	Municipality	Road Infrastructure Statistics	Ministry of Land, Infrastructure, Transport and Tourism
	Paved Road Length	Municipality	Road Infrastructure Statistics	Ministry of Land, Infrastructure, Transport and Tourism
	Number Of Parks	Municipality	Park Statistics	Ministry of Land, Infrastructure, Transport and Tourism
	Area Of Parks	Municipality	Park Statistics	Ministry of Land, Infrastructure, Transport and Tourism
	Number Of Police Stations	Municipality	Prefecture Statistics	Prefecture Office
Eldery Service	Number Of Nursing Homes	Municipality	Report on Public Health Administration and Services	Ministry of Health, Labour and Welfare
	Number Of Community Centers	Municipality	Social and Education Statistics	Ministry of Education, Culture, Sports, Science and Technology
	Number Of Senior Citizen Clubs	Municipality	Prefecture Statistics	Prefecture Office
Child/Education	Number Of Daycares	Municipality	Social and Wlfare Statistics	Ministry of Health, Labour and Welfare
	Number Of Schools (Elementary, Middle, and High)	Municipality	Prefecture Statistics	Prefecture Office
	Number Of Teachers (Elementary, Middle, and High)	Municipality	School Statistics	Ministry of Education, Culture, Sports, Science and Technology
Health/Medical	Number Of General Hospitals	Municipality	Survey of Medical Institutions	Ministry of Health, Labour and Welfare
	Number Of General Clinics	Municipality	Survey of Medical Institutions	Ministry of Health, Labour and Welfare
	Number Of Medical Doctors	Municipality	Statistics of Physicians, Dentists and Pharmacists	Ministry of Health, Labour and Welfare
	Number Of Nurses	Municipality	Prefecture Statistics	Prefecture Office

Table A.2: PCA Loading for Amenity Categories

	Loading
Panel A. Retail	
Number Of Retail Stores	.418
Number of Clothing Stores	.411
Number of Food and Beverage Retail Stores	.411
Number Of Restaurants	.411
Number Of Large Retail Stores	.384
Number Of Barber Shops And Beauty Parlors	.413
Panel B. Health Medical	
Number Of General Hospitals	.477
Number Of General Clinics	.505
Number Of Medical Doctors	.517
Number Of Nurses	.499
Panel C. Elderly Service	
Number Of Community Centers	.547
Number Of Senior Citizen Clubs	.632
Number Of Nursing Homes	.550
Panel D. Child Education	
Number Of Daycares	.567
Number Of Schools (Elementary, Middle, and High)	.576
Number Of Teachers (Elementary, Middle, and High)	.589
Panel E. Environment / Transportation	
Road Length	.526
Paved Road Length	.564
Number Of Parks	.394
Number of Police Stations	.500

B Appendix for Reduced-Form Facts

B.1 Aggregate Statistics

Figure B.1: Life Expectancy and Fertility Rates

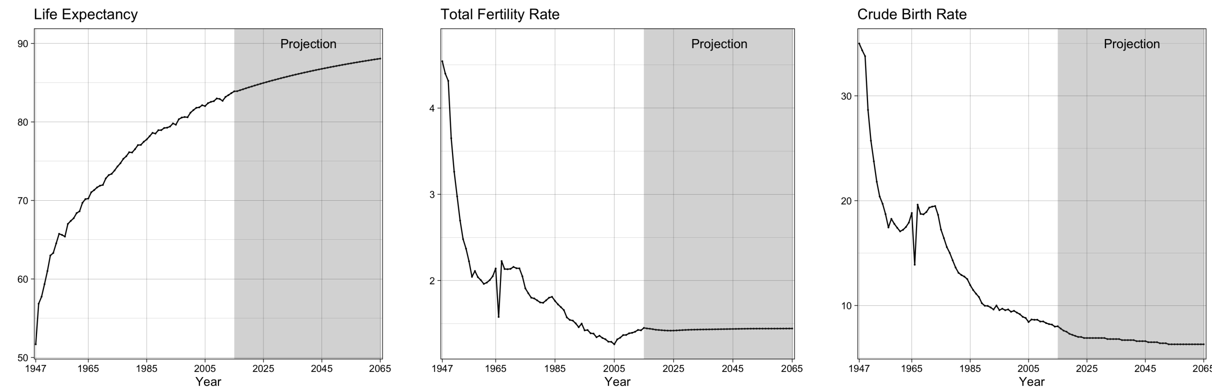
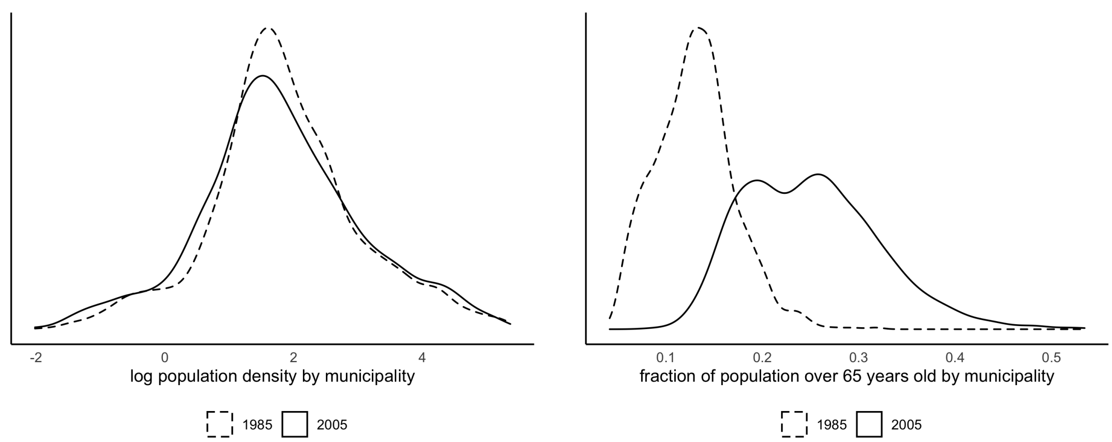


Figure B.2: Heterogeneity of Depopulation and Aging across Municipalities in Japan

(a) Population Density (b) Fraction of Population above 65 Years Old



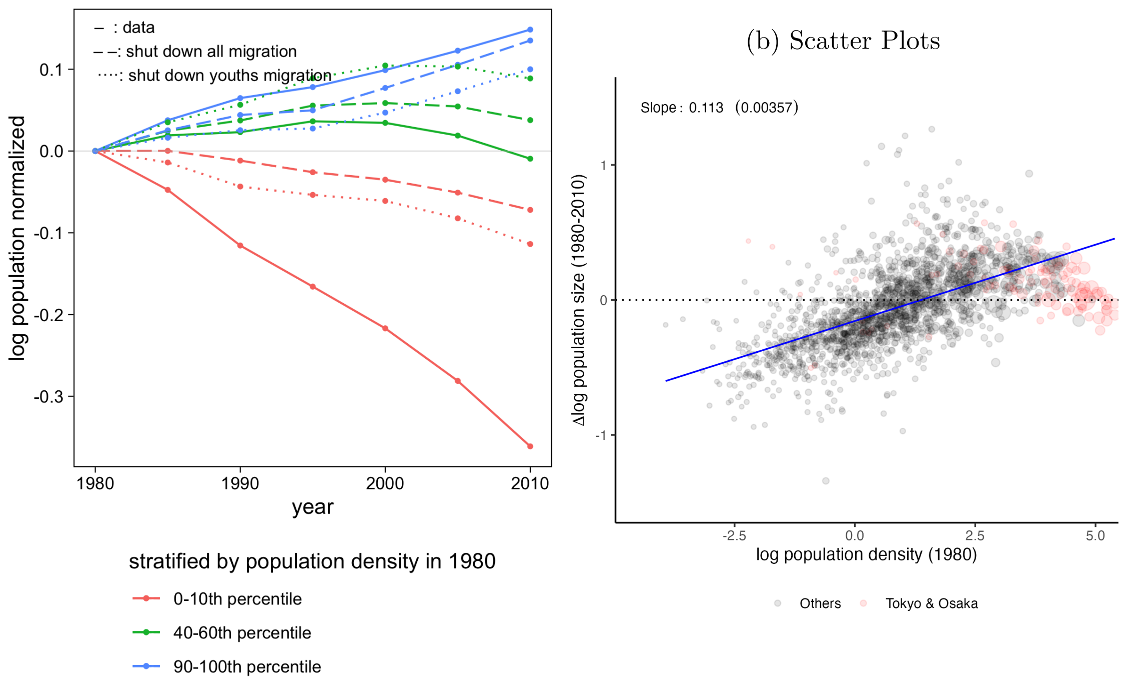
Note: This figure reports the distribution of population densities across Japanese municipalities in 1985 and 2005 in panel a. Panel b reports the distribution of fraction of population above 65 years old across Japanese municipalities.

B.2 Geographic Pattern of Depopulation and Aging

Figure B.3: Changes in Population Size across Municipalities and Role of Migration: Additional Heterogeneity across Population Density in 1980

(a) Add Median Population Density in 1980

(b) Scatter Plots



Note: Panel (a) reports a version of Figure 3 to include the patterns of municipalities with median (40-60) percentile in terms of population density in 1980. Panel (b) reports the relationship between the log change in population size from 1980 to 2010 against the log population density in 1980. Population density is defined by the population size divided by geographic area. The size of the dot corresponds to the population size of the municipality in 1980. Municipality boundaries are defined at the point of 2010.

B.3 Impacts of Depopulation and Aging

B.3.1 Additional Figures for First Stage

Figure B.4: Predicted Population Size Change and Aging

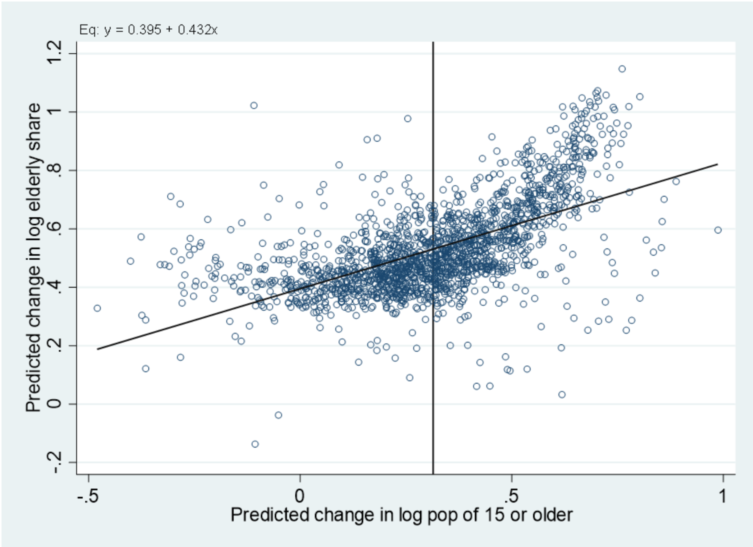
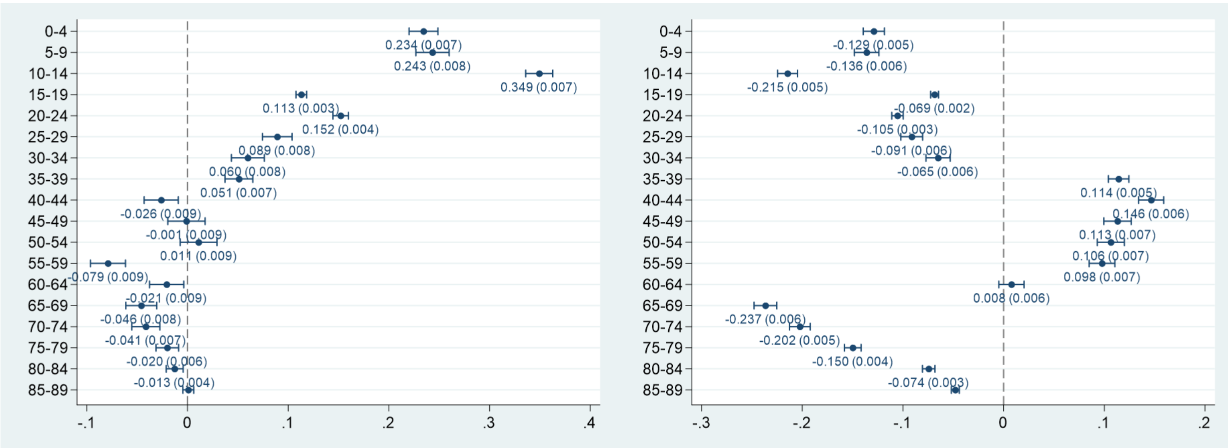


Figure B.5: Sources of Variation of IV from Population Pyramids in 1980

(a) Δ log Population (b) Δ log Fraction on Elderies



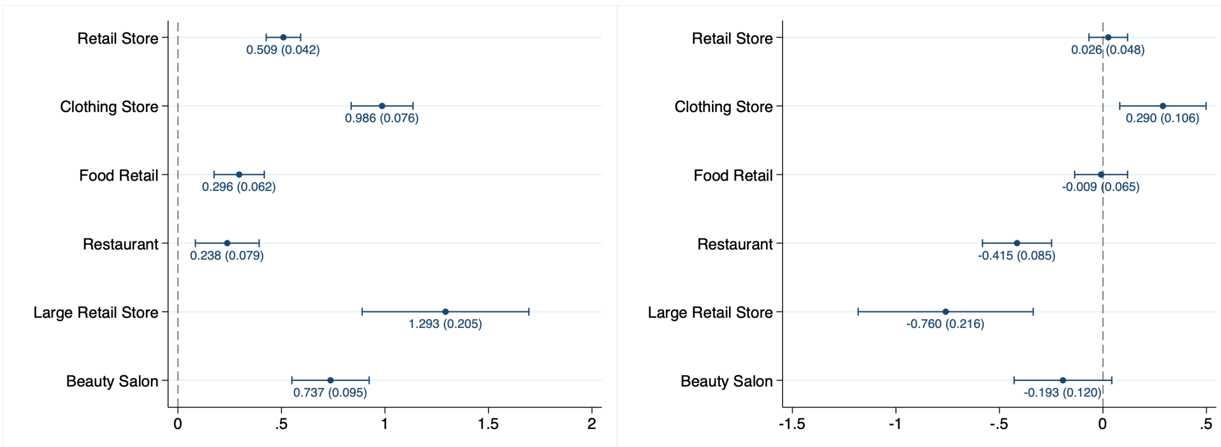
Note: This figure plots the coefficients on the following regression:

$$\ln L^n_{1980}(a) = \beta_1 \Delta \ln \widetilde{Pop(age \geq 15)}_n + \beta_2 \Delta \ln \widetilde{Pop(age \geq 65)_n / Pop(age \geq 15)}_n + \varepsilon_n(a),$$

B.3.2 Additional Figures for Second Stage

Figure B.6: Impacts of Depopulation and Aging on Local Economy: Retail

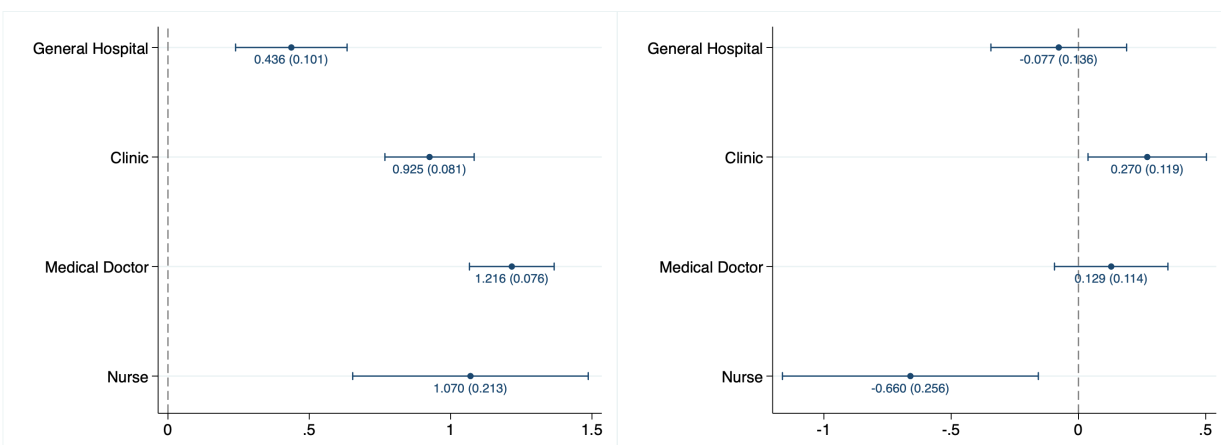
(a) Δ log Population (b) Δ log Fraction on Elderies



Note: This figure reports the coefficient estimates of equation 2 where each dependent variable is in changes of local economy such as retail. The left panel reports the coefficients on Δ log population and the right panel reports the coefficients on Δ log fraction of the elderly.

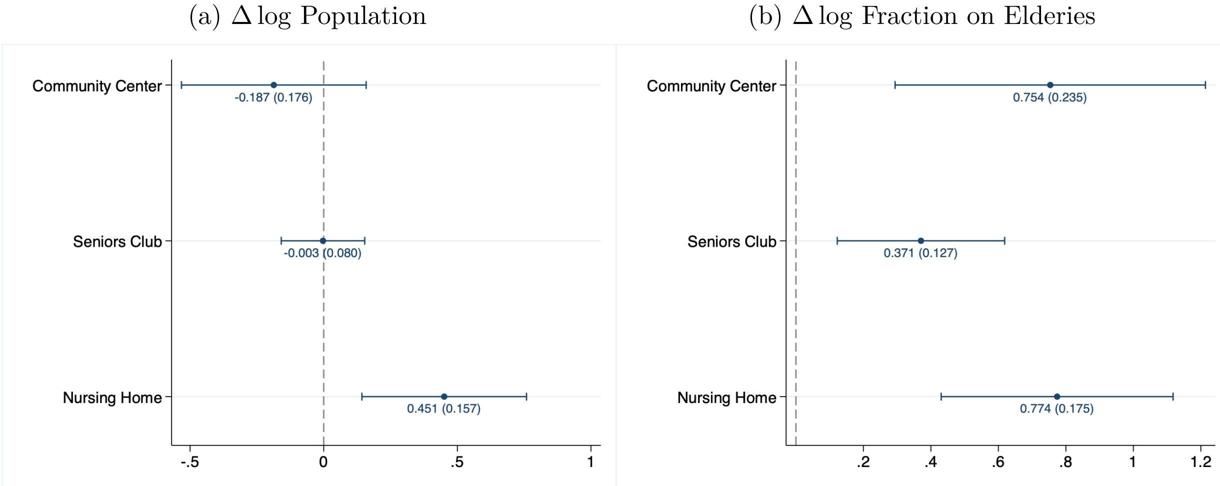
Figure B.7: Impacts of Depopulation and Aging on Local Economy: Health/Medical

(a) Δ log Population (b) Δ log Fraction on Elderies



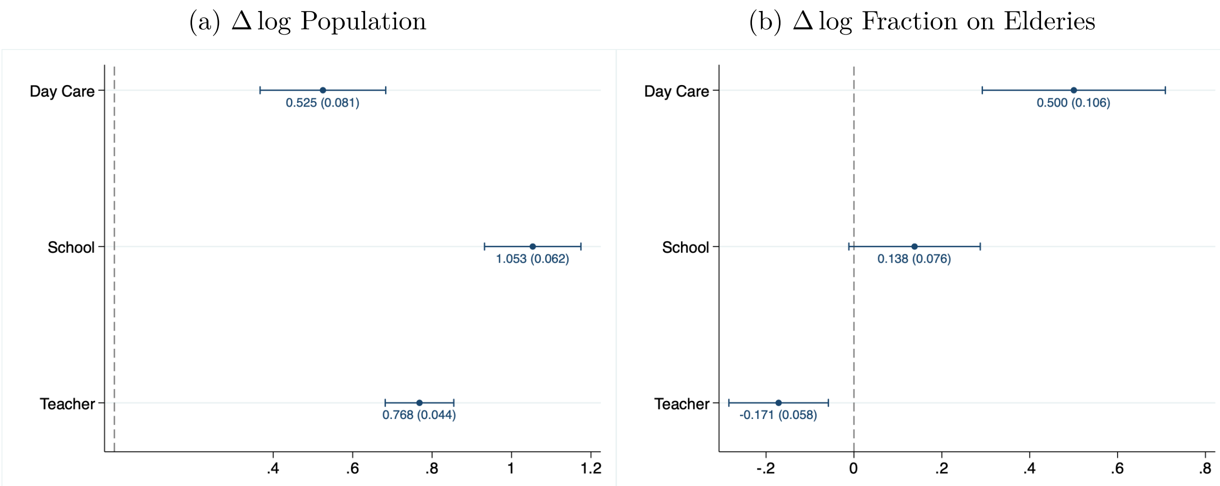
Note: This figure reports the coefficient estimates of equation 2 where each dependent variable is in changes of local economy such as health and medical services. The left panel reports the coefficients on Δ log population and the right panel reports the coefficients on Δ log fraction of the elderly.

Figure B.8: Impacts of Depopulation and Aging on Local Economy: Elderly Service



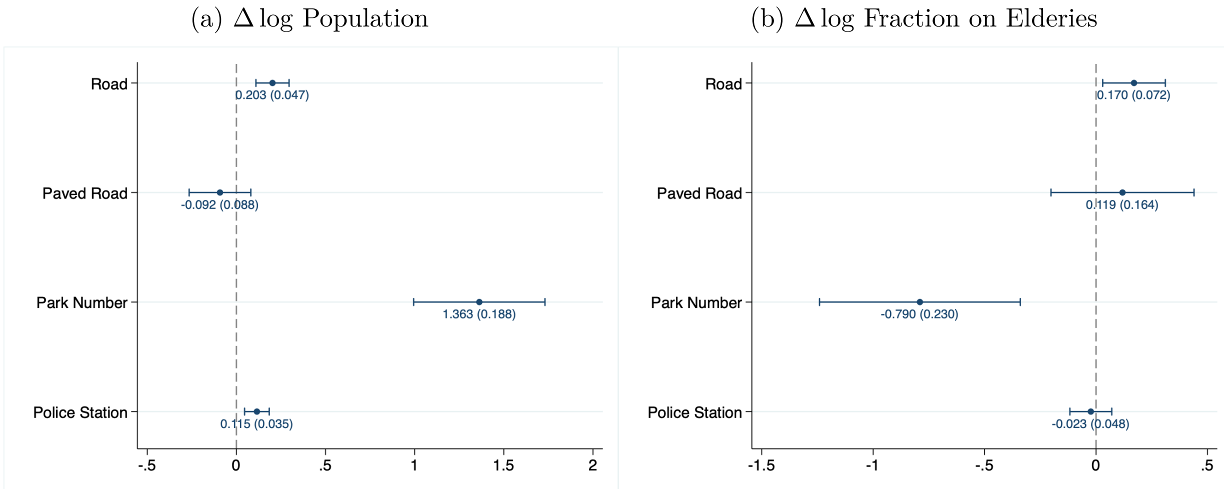
Note: This figure reports the coefficient estimates of equation 2 where each dependent variable is in changes of local economy such as elderly services. The left panel reports the coefficients on Δ log population and the right panel reports the coefficients on Δ log fraction of the elderly.

Figure B.9: Impacts of Depopulation and Aging on Local Economy: Child/Education



Note: This figure reports the coefficient estimates of equation 2 where each dependent variable is in changes of local economy such as child/education. The left panel reports the coefficients on Δ log population and the right panel reports the coefficients on Δ log fraction of the elderly.

Figure B.10: Impacts of Depopulation and Aging on Local Economy: Environment/Transportation



Note: This figure reports the coefficient estimates of equation 2 where each dependent variable is in changes of local economy such as public services. The left panel reports the coefficients on Δ log population and the right panel reports the coefficients on Δ log fraction of the elderly.