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Aging and public financing costs: Evidence from U.S. municipal bond markets ☆

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ABSTRACT

We examine the impact of population aging on municipal access to credit. A one standard deviation increase in a state's population age leads to a 23 basis point increase in municipal bond issue spread. Three mechanisms drive this effect: income tax revenue, healthcare spending, and pension liabilities. Constitutional pension protections and securities with lower credit quality or longer maturity exacerbate the effect. To control for endogenous migration and mortality patterns, we exploit variation from historical state fertility trends. Our findings highlight the challenges municipalities face to cope with systemic demographic transition.

1. Introduction

The baby boom following World War II profoundly shifted the age distribution of the U.S. population. The "population pyramid" will transform from its 1980s triangular shape to a nearly rectangular shape in 2040 (see Fig. 1). This transformation reflects that the proportion of individuals aged 80 or over has risen from 2 percent in 1980 to 4 percent today and will reach nearly 8 percent by 2040 (U.S. Census, 2018). The increasingly aging population can have important influences on the long-term fiscal future of the state and local governments (Stowe et al., 2012; Barth et al., 2016). Credit rating agencies cite population aging as a "non-traditional driver of fundamental credit risk", and municipal bond analysts rank demographic shifts as one of the most important issues facing the municipal bond market today.[1]

We quantify the economic impact of population aging on state and municipal governments' financial prospects through the lens of their municipal bond market outcomes. Using variation in state population aging rate stemming from historical fertility trends, we examine the causal effect of population aging on the price of municipal bond issuance and the mechanisms underlying the effect. Theory and evidence suggest an ambiguous relationship between aging and public financing costs. On the one hand, an older population could lead to higher retiree liabilities and lower tax revenue for state and municipal governments, thus increasing the likelihood of debt defaults and raising bond spreads (e.g., Feyrer, 2007; Novy-Marx and Rauh, 2012; Maestas et al., 2016; Boyer, 2019). On the other hand, if investors decrease their financial portfolio risk as they age, an older population would increase investor demand for relatively safe local municipal bonds, and consequently reduce bond spreads (e.g., Jagannathan and Kocherlakota, 1996; Bodie and Crane, 1997; Back et al., 2019).

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[1] See https://events.moodys.io/events/pfg2019 and https://www.smithsresearch.net/2019-analysts-survey/.

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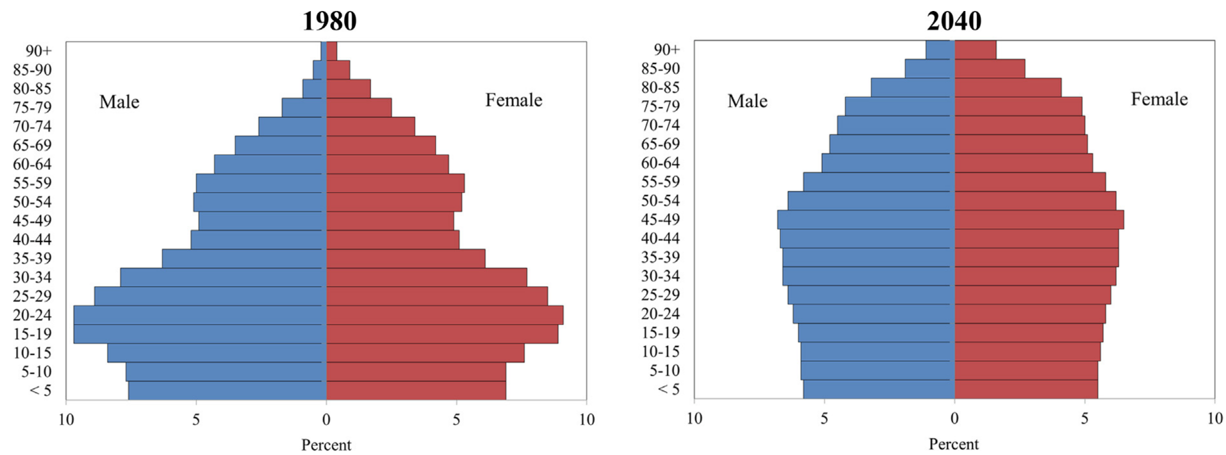

Fig. 1. Population Pyramid of the United States in 1980 and 2040 (projected). These figures plot the population pyramid of the United States in 1980, and the projected population pyramid in 2040. We collect data on population projections in 2040 from U.S. Census Bureau's National Population Projections Data Tables. The left and right side of each graph plots the fraction of male and female population, respectively, by 5-year age intervals.

We use a sample of over 100,000 newly issued bonds by U.S. state and local governments between 1996 and 2016 to test the effect of population aging on public financing costs. The baseline OLS regressions show that the fraction of state population above 65 has a statistically significant positive relation to state and local government bond issue spreads. The regressions control for various state and bond characteristics, as well as state, year, and month fixed effects. The state fixed effects absorb persistent state characteristics such as natural resources endowments, climate patterns, and government fiscal institutions that might simultaneously affect state demographics and finances. The year and month fixed effects absorb nationwide variation in economic conditions and seasonality in the bond market.

The positive association we observe in the OLS regressions is unlikely to represent the causal impact of population aging. Retirees migrate to states with better economic conditions that OLS tests may not adequately control for. Average life expectancy could be higher in states with better government financial conditions and healthcare infrastructure. Municipalities with different age demographics may choose to issue more or fewer bonds based on the demand to support that population or the anticipated ability to service debt claims with a higher or lower tax base.

To isolate exogenous variation in states' share of senior population, we construct an instrumental variable (IV) using the sum of birth rates from year *t*-65 to *t*-74 in a state. The cutoffs are motivated by the earliest retirement age to receive full social security benefits and the average life expectancy at the beginning of our sample, respectively.[2] Due to states' heterogeneous exposure to the post-WWII baby booms, the IV has substantial cross-sectional and time-series variability during our sample period, allowing for the inclusion of a similar set of state and time fixed effects to adjust for persistent state characteristics and macroeconomic trends.

The identifying assumption for our instrumental variable analysis is that birth rates from several decades prior only affect current bond spreads through the age structure of the population, after controlling for state and time fixed effects and other covariates. The assumption is plausible because any state-level factors that can affect both historical birth rates and current bond spreads must persist for more than 65 years, and therefore should be accounted for by state fixed effects. We elaborate on the validity and interpretation of the IV results below.

The two-stage IV estimation results show that a one standard deviation increase in the fraction of population above 65—comparable to the difference between California (relatively young) and New York, or New York and Arizona (relatively old)—leads to a 23–24 basis point increase in state and local government bond spreads. This effect is similar in magnitude to a credit rating downgrade of three-notches. In dollar terms, the magnitude reflects an additional $71 million in annual interest payment for an average state. This cost is equivalent to building 36 miles of new rural roads (enough to traverse most counties in the U.S.) or treating 35 billion gallons of water.[3]

It is not surprising that the IV estimates are larger in magnitude than the OLS estimates. The IV approach isolates one and only one economic channel (the aging of existing residents) through which population changes affect municipal finance, whereas the OLS approach identifies equilibrium effects that include other offsetting mechanisms, such as migration of retirees and young talent. Both the IV and the OLS results suggest that the negative impact on municipal bond yields brought by an aging population, such as through the effect on state revenues and liabilities, outweigh the positive impact, such as through rising demand for safe assets. Consistent with aging increasing the default risk of state and local government debt, we also document that the effect is more pronounced among bonds with lower credit quality and longer maturity.

What mechanisms drive this effect? We test three hypotheses related to state and local governments' revenue and cost channels. The first hypothesis is that an older population reduces state tax revenue, the primary source of funding for municipal bond payments (Moody's (2017)), and therefore increases bond default risks. Aging decreases labor productivity and labor force participation, and consequently reduces the overall size of the economy, the ultimate tax base for governments (Hansen, 1939; Feyrer, 2007; Maestas et al., 2016). Furthermore, workers' earnings peak in their 40s (Murphy and Welch, 1990), which implies a negative association between the fraction of elderly and income tax revenue.

The second hypothesis is that aging increases public financing costs through unfunded pension obligations. Because public pen-

[2] The full retirement age is 65 for individuals born before 1937 and 67 for individuals born after 1960. See https://www.ssa.gov/planners/retire/agereduction.html.

[3] We obtain road construction cost-per-mile estimates from the Florida Department of Transportation (fdot.gov/programmanagement/estimates/lre/costpermile-models/cpmsummary.shtm), average county land area from the Census (census.gov/library/publications/2011/compendia/usa-counties-2011.html), and water treatment cost from the following website: safewater.zendesk.com/hc/en-us/articles/211400478-How-much-does-it-cost-to-treat-and-deliver-drinking-water-.

sion benefits are constitutionally protected in many states, retiree payments can crowd out bondholder payments in fiscal crises and increase the default risks of municipal bonds. Novy-Marx and Rauh (2012) and Boyer (2019) find empirical evidence consistent with this crowding out effect. We build on their evidence to develop our second hypothesis.

The third hypothesis is that aging raises state borrowing costs through healthcare spending and liabilities. Hospital and healthcare spending represent a significant portion of overall public spending. Furthermore, most state and local governments provide public employees with other post-employment benefits (OPEBs) that primarily consist of health insurance. Total state and local unfunded OPEBs were around $860 billion in 2016 and could add significant financial burdens to state and local governments (Munnel et al., 2016).

We find empirical evidence consistent with all three channels. We document that the impact of aging on government financing cost is twice as large among states with constitutional pension protections, providing support for the pension liability channel. Furthermore, we find that a one standard deviation increase in the proportion of population above 65 leads to a 10.9% reduction in personal income tax revenue, a 19% increase in pension liability-to-GDP ratio, a 22% increase in hospital spending, and a 28.1% reduction in retiree healthcare funding.

Last, we find suggestive evidence of a chain of causation that runs from aging to subsequent channels and then to bond spreads. We successively control for measures of the intermediate channels in the main IV regression, and examine whether and how much the coefficient on aging (i.e., the main effect) decreases. We discuss this procedure and its underlying econometric assumptions in more detail in Section 4. Our results suggest that the channel of reduced tax revenue and pension funding each explains around 30% of the overall effect, whereas the channel of healthcare underfunding explains around 10%.

Our paper joins others examining the determinants of municipal bond issuance yields. These factors include the location of the bond underwriter (Butler, 2008), market transparency (Schultz, 2012), exogenous rating change (Adelino et al., 2017), climate risk (Painter, 2020), pension underfunding (Novy-Marx and Rauh, 2012; Boyer, 2019), and state political economy (Poterba and Rueben, 2001; Butler et al., 2009; Gao et al., 2019, 2020). We identify the age structure of the population as another fundamental and important factor.

Our work also extends the literature on the effect of demographics on financial asset returns. While there is substantial literature on the impact of age structure shifts on stock returns (Bakshi and Chen, 1994; Erb et al., 1997; Abel, 2001, 2003; Poterba, 2001; Geanakoplos et al., 2004; Goyal, 2004; Ang and Maddaloni, 2005; DellaVigna and Pollet, 2007), relatively little evidence exists in the bond market. Even among the existing evidence on bond returns (Poterba, 2001; Geanakoplos et al., 2004), the authors focus on how aging impacts asset demand, rather than a mechanism that is directly related to the risk of the underlying asset cash flows.

2. Measures, data and sample

2.1. Measures of aging and bond Yield Spread

Following the literature on the economics of aging, such as Weil (1999) and Maestas et al. (2016), we measure population aging using the aged dependency ratio—the ratio of retirement age population to working age population. It is defined as:

$$\text{Aged dependency ratio } = \frac{\text{Population 65+}}{\text{Population 15-64}} \tag{1}$$

The ratio describes how much pressure an economy faces in supporting its senior population. The cutoff of 65 years of age is motivated by the earliest retirement age to receive full social security benefits set by the Social Security Administration.[4] The cutoff of 15 years of age is motivated by both the Fair Labor Standards Act, which sets 14 years of age as the minimum age for employment, and the limitations of our dataset, which contains annual population data at five-year age intervals.[5]

We calculate bond yield spread as the difference in yields between a municipal bond and a synthetic treasury bond with equivalent coupon and maturity date. We use the following calculation procedure. First, for each municipal bond, we solve for the theoretical price on a synthetic treasury bond with the same maturity date and coupon rate by calculating the present value of its coupon payments and face value using the U.S. Treasury yield curve:

$$P_N^T = \sum_{n=1}^{N} \frac{\frac{C}{2}}{\left(1+\frac{r_n^T}{2}\right)^n} + \frac{100}{\left(1+\frac{r_N^T}{2}\right)^N} \tag{2}$$

where $\{r_n^T\}$ is the set of treasury spot rates estimated in Gürkaynak et al. (2007). Then, we calculate the yield-to-maturity of the synthetic Treasury bond using this price, the coupon payments, and the face value. Last, we take the difference between the municipal bond yield and the synthetic Treasury bond yield. This procedure is similar to the yield spread calculation in Longstaff et al. (2005), Ang et al. (2014), and Gao et al. (2019).

To account for features of municipal bonds that are different from Treasury securities, we calculate the tax-adjusted yield spread by taking the difference between the municipal bond yield and the after-tax synthetic Treasury yield. This adjustment is motivated by the observation that 87% of the municipal bonds in our sample are exempt from federal income tax, whereas Treasury bonds are rarely tax-exempt. We do not adjust for state income tax exemption for two reasons. The first reason is that municipal bonds are typically exempt from state income tax only for in-state investors, but we cannot observe the proportion of in-state bondholders.[6] The second reason is that state income tax exemption laws include multiple exceptions that vary from state to state, making it difficult to apply a uniform treatment (Babina, et al., 2021).

2.2. Municipal bond issuance data

We obtain data on municipal bond issuances from the Securities Data Company's (SDC) Global Public Finance U.S. New Issues database. We collect data on various bond characteristics for municipal bonds issued by state and local governments between 1996 and 2016, such as issuer, issue date, issue size, yield to maturity, coupon rate, maturity date, embedded options, credit enhancement information, and tax treatment.

The municipal bond literature informs important choices we make in our sample construction procedure (Novy-Marx and Rauh, 2012; Schwert, 2017; Boyer, 2019). First, we exclude any observations with coupon rates greater than 20%, yield to maturity greater than 50%, or price less than 50 (i.e., 50% of face value) or greater than 150, as these are likely to be data errors. These obser-

[4] The Social Security Administration webpage describes the age at which a person may first become entitled to full retirement benefits: https://www.ssa.gov/planners/retire/agereduction.html.

[5] The U.S. Department of Labor webpage that describes age requirement for employment can be found here: https://www.dol.gov/general/topic/youthlabor/agerequirements.

[6] As of 2015, five states tax in-state municipal bonds: Oklahoma, Utah, Iowa, Wisconsin and Illinois. Washington D.C. does not tax in-state or out-of-state municipal bonds. See https://www.municipalbonds.com/tax-education/tax-exemption-from-state-income-taxes/.

vations constitute less than 1% of our sample. Second, we limit our analysis to General Obligation municipal bonds, which are not secured by any special purpose revenue. Third, we exclude bonds with variable coupon rates, because the yield spread to Treasury on these bonds are difficult to calculate accurately. Fourth, we winsorize all yield and yield spread variables at 1% and 99% over the sample period to mitigate the impact of outliers.

Our final sample consists of 102,854 General Obligation bonds issued by U.S. states (including the District of Columbia), counties, cities, districts, and other governmental entities from 1996 to 2016. While our main sample includes both tax-exempt and taxable municipal bonds, in the Appendix Table A9 we re-run our estimations excluding taxable bonds, which are often private activity bonds that may not be comparable to rest of the General Obligation bonds sample. Our conclusions are unchanged when we omit taxable bonds.

2.3. State characteristics data

We obtain state population data by age from the Census Bureau to construct our main variable of interest—the ratio of retirement age to working age population. To control for factors that may affect both aged dependency ratio and state and local debt spreads, we collect data on interstate migration flows from the Internal Revenue Service, mortality rates from the Center for Disease Control and Prevention (CDC), state personal income tax rates from the National Bureau of Economic Research's TAXSIM program, and state corporate income tax rates from the University of Michigan's World Tax Database and the Tax Foundation. We use state maximum personal income tax rates instead of average personal income tax rates as a control variable in all our analysis because municipal bond retail investors are typically individuals in the top income brackets (Ang et al., 2010; Longstaff, 2011).

To isolate exogenous variation in population aging determined by historical fertility trends, we use historical birth rates as our instrumental variable. We discuss the details regarding the empirical specification and identification in Section 3.3. We collect historical birth rates and infant mortality rates for each state from 1922 to 1951 from the CDC's annual *Vital Statistics of the United States* publications. However, not all states joined CDC's birth registration starting from 1922. Specifically, by 1922, 31 states and the District of Columbia registered their birth and infant mortality with CDC; by 1933, the entire United States is registered except for Alaska and Hawaii.[7] Because Alaska and Hawaii did not register with the CDC until after 1960, we exclude them from our sample.

If the staggered inclusion of states in birth registration is correlated with unobservable state characteristics that can affect borrowing cost, then our IV estimates would suffer from sample selection biases. However, any state characteristics that affect both birth registration inclusion during 1922–1933 and borrowing cost during 1996–2016 must be highly persistent and thus are likely absorbed by state fixed effects. Therefore, controlling for state fixed effects, the sample selection procedure is unlikely correlated with omitted variables that could affect the outcome of this study.

To explore mechanisms that may drive the relationship between aging and bond spreads, we use a variety of data sources. We obtain data on state and local governments' tax revenue, hospital expenditure, and health expenditure from the Census' Annual Survey of State and Local Government Finances. We adjust for inflation for all government finance variables using the CPI index with the base year of 2000 published by the Bureau of Labor Statistics. We collect pension liability data from the Center for Retirement Research at the Boston College. The data are available starting from 2001 and contain annual public pension plans' liabilities. We aggregate pension liabilities across plans in a state in a year, and normalize it by the state's GDP. To measure state-level government retiree healthcare benefits funding status, we collect data on state OPEB funding ratios from 2010 to 2016 from the Pew Charitable Trusts. OPEB are primarily healthcare benefits that state and local governments provide to their retired employees. The Governmental Accounting Standards Board (GASB) has required all levels of government to report their OPEB assets and liabilities since 2008.

2.4. Descriptive Statistics

Tables 1 and 2 present descriptive statistics for our sample. Table 1 shows the summary statistics for our entire sample, and Table 2 breaks down the data into 5-year time intervals.

As shown in Table 2, the national trend of population aging, measured by the aged dependency ratio, shows a decrease from 1996 to 2005, followed by an increase from 2006 to 2010, and an accelerated increase from 2011 to 2016. Furthermore, the percentage of population that is 65 or older comoves with historical birth rates. The magnitude of the former is about 65% of the latter, reflecting the average life expectancy of around 65 years for the cohorts born between 1922 and 1951.[8]

The accelerated population aging rate from 2011 to 2016 coincides with a period of slow state and local tax revenue growth. State and local government real tax revenue per capita had been increasing at a rate of roughly 10% every 5 years prior to 2010, but only 2% after 2010. This phenomenon is consistent with the argument that aging reduces the tax base of state governments. The state average pension funding ratio has been declining since 2001, but the state average retiree healthcare (OPEB) funding ratio has been increasing since GASB required states to report their retiree healthcare assets and liabilities. The level of retiree healthcare funding varies substantially across states, reflected by the fact that the standard deviation of the retiree healthcare funding ratio is twice as big as the average.

To shed light on the heterogeneous regional patterns of population aging, in Fig. 2 we present the choropleth maps of the aged dependency ratio in 1980 (Panel A), 2016 (Panel B), and the projected level of aged dependency ratio in 2040 (Panel C). The population projections by age are obtained from the Demographics Research Group at the University of Virginia Weldon Cooper Center for Public Service.[9] We use the same color legend across all years to facilitate comparison. The overall color of the map becomes visibly darker through time. In 2016, Florida has the highest ratio of the elderly to working age population, 31%, but Maine will replace its position in 2040, reaching an aged dependency ratio as high as 50%. The 50% aged dependency ratio implies that for every two working-age population in the state, there is a senior person that is 65 or older. Utah, Texas, and the District of Columbia are among the jurisdictions with low aged dependency ratios consistently throughout time. Between 1980 and 2040, 24 states will experience over 100% growth rate in aged dependency ratios, whereas District of Columbia will experience a decrease.

In our sample of municipal bonds issued by state and local governments, the median bond has a par value of 5 million dollars and 15 years to maturity. The median yield spread during the sample period between 1996 and 2016 is −0.1 percentage points, and

[7] See Shapiro (1950) "Development of Birth Registration and Birth Statistics in the United States" for description of how CDC's coverage spread through states.

[8] See https://u.demog.berkeley.edu/~andrew/1918/Fig. 2.html.

[9] Retrieved from https://demographics.coopercenter.org/national-population-projections.

Table 1

Summary Statistics. This table reports summary statistics for state and bond characteristics. The sample for the state characteristics contains all states (including the District of Columbia and excluding Alaska and Hawaii) between 1996 and 2016. The sample for bond characteristics contains 102,854 General Obligation bonds issued by all U.S. state and local governments (including the District of Columbia and excluding Alaska and Hawaii) and state authorities during the same period. The observation numbers are smaller in some rows due to data availability constraints. Aging is the ratio of the population above 65 to the population between the ages of 15 and 64. The rate of a variable is defined as the level of the variable per 100 population. Historical Birth Rate is the sum of birth rates netting of infant mortality in the 10-year period from *t*-65 to *t*-74 years in a state. Net Migration Rate is Migration Inflow Rate minus Migration Outflow Rate. All revenue variables are deflated using the CPI Index. OPEB is the acronym of other post-employment benefits. Pension Liability Ratio is the ratio of pension assets divided by state GDP. OPEB Funding Ratio is the ratio of OPEB asset to OPEB liabilities. Yield Spread is the difference between yields of a municipal bond and a coupon and maturity-equivalent synthetic Treasury bond. Tax-Adjusted Yield Spread makes adjustments to yield spread calculations by accounting for muni tax benefit. Taxable Bonds, Credit Enhancement Bonds, Callable Bonds, and Competitive Bid are the percentage of bonds that are taxable, credit enhanced, callable and sold through competitive bidding, respectively.

	Mean	Median	SD	P1	P99	N
State Demographic Characteristics						
Aging (%)	20.1	20.0	3.0	13.7	28.8	1,029
Percent Population 15–64 (%)	66.5	66.5	1.5	63.4	72.5	1,029
Percent Population 65+ (%)	13.4	13.3	1.8	8.8	18.3	1,029
Historical Birth Rate (%)	19.7	19.1	3.8	13.4	30.0	934
Mortality Rate (%)	0.9	0.9	0.1	0.5	1.2	1,029
Migration Inflow Rate (%)	2.5	2.3	1.0	1.0	6.1	1,029
Migration Outflow Rate (%)	2.4	2.2	0.9	1.3	6.8	1,029
Net Migration Rate (%)	0.1	0.0	0.5	−1.1	1.6	1,029
State Economic Characteristics						
Tax Revenue Per Capita ($)	3,167.8	2,932.8	886.8	2,114.7	6,753.5	1,029
Income Tax Revenue Per Capita ($)	796.1	778.2	486.6	0.0	2,384.4	1,029
Personal Income Tax Revenue Per Capita ($)	680.6	683.3	427.6	0.0	1,875.3	1,029
Pension Liability Ratio (%)	21.1	20.1	7.3	4.7	38.9	778
OPEB Funding Ratio (%)	9.23	1.0	17.2	0.0	70.9	322
Maximum Personal Income Tax Rate (%)	5.3	6.0	2.9	0.0	10.9	1,029
Maximum Corporate Income Tax Rate (%)	6.5	7.0	2.9	0.0	12.0	1,029
Municipal Bond Issuance						
Number of Issuance Per State	109.5	57.0	138.7	1.0	579.0	1,029
Total Amount of Issuance Per State ($ mil)	1,978.8	987.8	3,124.5	4.4	15,962.0	1,029
Issue Size ($ mil)	18.5	5.2	81.3	0.2	254.9	102,854
Years to Maturity	14.9	15.0	6.8	1.0	30.0	102,854
Raw Yield (%)	3.9	4.0	1.2	0.9	6.5	102,854
Yield Spread (%)	0.0	−0.1	0.8	−1.6	2.3	102,854
Tax-Adjusted Yield Spread (%)	1.4	1.4	0.7	0.2	3.7	102,854
Underwriter Gross Spread (%)	0.9	0.8	0.6	0.1	2.9	48,138
Taxable Bonds (%)	7.4	0.0	26.2	0.0	100.0	102,854
Credit Enhancement Bonds (%)	42.5	0.0	49.4	0.0	100.0	102,854
Callable Bonds (%)	72.7	100.0	44.6	0.0	100.0	102,854
Competitive Bid (%)	46.8	0.0	49.9	0.0	100.0	102,854

the median tax-adjusted yield spread is 1.4 percentage points. The difference between the two reflects the tax benefits of municipal bonds.

In all regression specifications, we control for various bond issue characteristics including whether a bond is taxable, callable, sold through competitive bidding, has any credit enhancement features (such as bond insurance and guarantees), and the years-to-maturity of a bond. In the Appendix Table A8 we also control for bond maturity in a non-linear way using years-to-maturity fixed effects. The issuance of taxable bonds increased from about 4% prior to the financial crisis to approximately 8% after. The use of bond credit enhancement increased by about 15% from 1996 to 2005, but decreased over 40% after the financial crisis, reflecting the contraction of the bond insurance industry after 2007.

Municipalities may choose underwriters through either negotiated or competitive offerings. A negotiated offering occurs when the issuer and an underwriter come to a contractual agreement that the underwriter will have exclusive rights to distribute the issue. In a competitive offering, multiple underwriters bid for the right to issue the bond, with the winning bid being the one with the lowest issuance cost to the municipality. Controlling for the type of underwriting procedure is important, as the type of offering is an important factor in the cost of the issue (Joehnk and Kidwell, 1979; Cestau et al., 2020). Our sample of new issues consists of 47% competitive and 53% negotiated offerings.

3. Effect of aging on municipal bond market outcomes

3.1. Baseline OLS results

To assess the impact of population aging on the municipal bond market outcomes, we first estimate baseline OLS models of the form:

$$Bond\ Spread_{it} = \beta_0 + \beta_1 Aging_{st} + \beta_2^{'} X_{st}^1 + \beta_3^{'} X_{it}^2 + \eta_s + \eta_t + \eta_m + \epsilon_{it} \quad (3)$$

where we index bond by *i*, state by *s*, year by *t*, and month by m. Aging is measured by aged dependency ratio—the ratio of the population above 65 to the population between the ages of 15 and 64, defined mathematically in equation (1).

X_{st}^1 is a vector of state characteristics, comprising population, net migration rate, mortality rate, and income tax rate. We control for contemporaneous state annual migration rate because it could be correlated with state economic conditions (and consequently bond default risk) and population demographics. We also control for state income tax rate because previous literature shows that income tax plays an important role in driving interstate migrations (Moretti and Wilson, 2017; Fajgelbaum et al., 2019). We do not control for state labor force, employment, or income characteristics because these variables could themselves be driven by population

Table 2

Summary Statistics by 5-Year Time Periods. This table reports 5-year averages of state and bond characteristics. The sample for the state characteristics contains all states (including the District of Columbia and excluding Alaska and Hawaii) between 1996 and 2016. The sample for bond characteristics contains 102,854 General Obligation bonds issued by all U.S. state and local governments (including the District of Columbia and excluding Alaska and Hawaii) and state authorities during the same period. The observation numbers are smaller in some rows due to data availability constraints. Aging is the ratio of the population above 65 to the population between the ages of 15 and 64. The rate of a variable is defined as the level of the variable per 100 population. Historical Birth Rate is the sum of birth rates netting of infant mortality in the 10-year period from *t*-65 to *t*-74 years in a state. Net Migration Rate is Migration Inflow Rate minus Migration Outflow Rate. All revenue variables are deflated using the CPI Index. OPEB is the acronym of other post-employment benefits. Pension Liability Ratio is the ratio of pension assets divided by state GDP. OPEB Funding Ratio is the ratio of OPEB asset to OPEB liabilities. Yield Spread is the difference between yields of a municipal bond and a coupon and maturity-equivalent synthetic Treasury bond. Tax-Adjusted Yield Spread makes adjustments to yield spread calculations by accounting for muni tax benefit. Taxable Bonds, Credit Enhancement Bonds, Callable Bonds, and Competitive Bid are the percentage of bonds that are taxable, credit enhanced, callable and sold through competitive bidding, respectively.

	1996–2000	**2001–2005**	**2006–2010**	**2011–2016**
State Demographic Characteristics				
Aging (%)	19.5	18.9	19.5	22.2
Percent Population 15–64 (%)	65.9	66.8	67.2	66.2
Percent Population 65+ (%)	12.8	12.6	13.1	14.7
Historical Birth Rate (%)	18.3	17.3	19.0	22.9
Mortality Rate (%)	0.9	0.9	0.8	0.9
Migration Inflow Rate (%)	2.7	2.5	2.4	2.3
Migration Outflow Rate (%)	2.6	2.4	2.3	2.3
Net Migration Rate (%)	0.1	0.1	0.1	0.0
State Economic Characteristics				
Tax Revenue Per Capita ($)	2895.6	3017.6	3328.0	3386.1
Income Tax Revenue Per Capita ($)	759.1	743.9	830.6	841.6
Personal Income Tax Revenue Per Capita ($)	641.3	647.6	701.4	723.4
Pension Liability Ratio (%)		19.4	20.9	22.6
OPEB Funding Ratio (%)			7.3	9.5
Maximum Personal Income Tax Rate (%)	5.4	5.3	5.3	5.2
Maximum Corporate Income Tax Rate (%)	6.5	6.6	6.5	6.3
Municipal Bond Issuance				
Number of Issuance Per State	89.9	110.6	105.2	131.2
Total Amount of Issuance Per State ($ mil)	1138.3	1978.5	2237.1	2511.1
Issue Size ($ mil)	13.3	18.0	21.2	19.1
Years to Maturity	15.3	14.7	15.1	14.6
Raw Yield (%)	5.2	4.3	4.1	2.9
Yield Spread (%)	−0.9	−0.4	0.2	0.6
Tax-Adjusted Yield Spread (%)	1.5	1.3	1.5	1.5
Taxable Bonds (%)	3.7	4.4	11.9	7.8
Credit Enhancement Bonds (%)	49.0	55.8	41.2	32.5
Callable Bonds (%)	76.7	70.8	71.5	72.9
Competitive Bid (%)	57.8	46.2	43.7	44.7

aging, and therefore constitute potential channels instead of omitted variables. We also do not condition on bond credit rating because credit rating potentially reflects what we are trying to capture—a change in the default risk of state and local governments caused by population aging. Hence it would not be appropriate to hold credit rating constant (i.e. hold default risk constant) and compare the residual differences in bond spreads.[10]

X_{it}^2 is a vector of bond characteristics, including years to maturity and indicators for whether the bond is callable, taxable, credit enhanced, and sold through competitive bidding . η_s, η_t, and η_m denote state, year, and month fixed effects. We include them to account for national macroeconomic trends, monthly pricing anomalies, and time-invariant state characteristics, respectively. We cluster standard errors at the state-year level to control for within state-year residual correlation in bond issue spread.

Table 3 presents the coefficient estimates of the OLS regressions. The regression in Column (1) shows that a one standard deviation increase in aged dependency ratio is associated with a 6.5 basis points increase in bond raw yield. The coefficient estimates in Column (2) suggest that the effect is similar when we control for interest rate risk by replacing raw yield with yield spread to a matching Treasury bond. The results in Column (3) suggest that the effect is similar in magnitude after adjusting for the tax premium of tax-exempt municipal bonds.

To summarize, the OLS tests estimate a precisely measured, but economically small, negative effect of aging on local government borrowing cost. This small magnitude is consistent with the possibility, described in the introduction, that an aging population has both a positive effect on bond yield spreads through an increase in demand and a negative effect through a smaller tax base. Aside from these offsetting effects of aging on municipal bond yield spreads, the OLS point estimate is likely to understate the magnitude of the effect. That is because the demographic composition of a state's population is endogenous in nature—it is determined by unobserved state characteristics such as age-related migration and mortality patterns that can simultaneously affect our outcomes of interest. These omitted variables likely bias the coefficient on the aged dependency ratio toward zero. We discuss these endogeneity issues in detail in the next section.

3.2. Endogeneity issues with OLS specification

It is important to discuss potential reasons why the causal effect of aging on bond spread might differ from the baseline OLS estimates. Three major factors influence the size of state populations and their age distributions at any given point in time: historical trends in birth rates, mortality rates, and migration. If migration

[10] Although we deem controlling for bond ratings to be inappropriate for our research question, our results survive even after controlling for ratings. In untabulated tests, we find that a one standard deviation increase in the aged dependency ratio leads to a half notch increase (i.e., higher risk) in bond ratings. These results imply that rating agencies impound age-related credit risk into bond ratings, though the markets' assessment of such risk appears to be higher. We caution that these results should be taken as only suggestive due to the high number of missing observations (around 40%) in SDC rating variables.

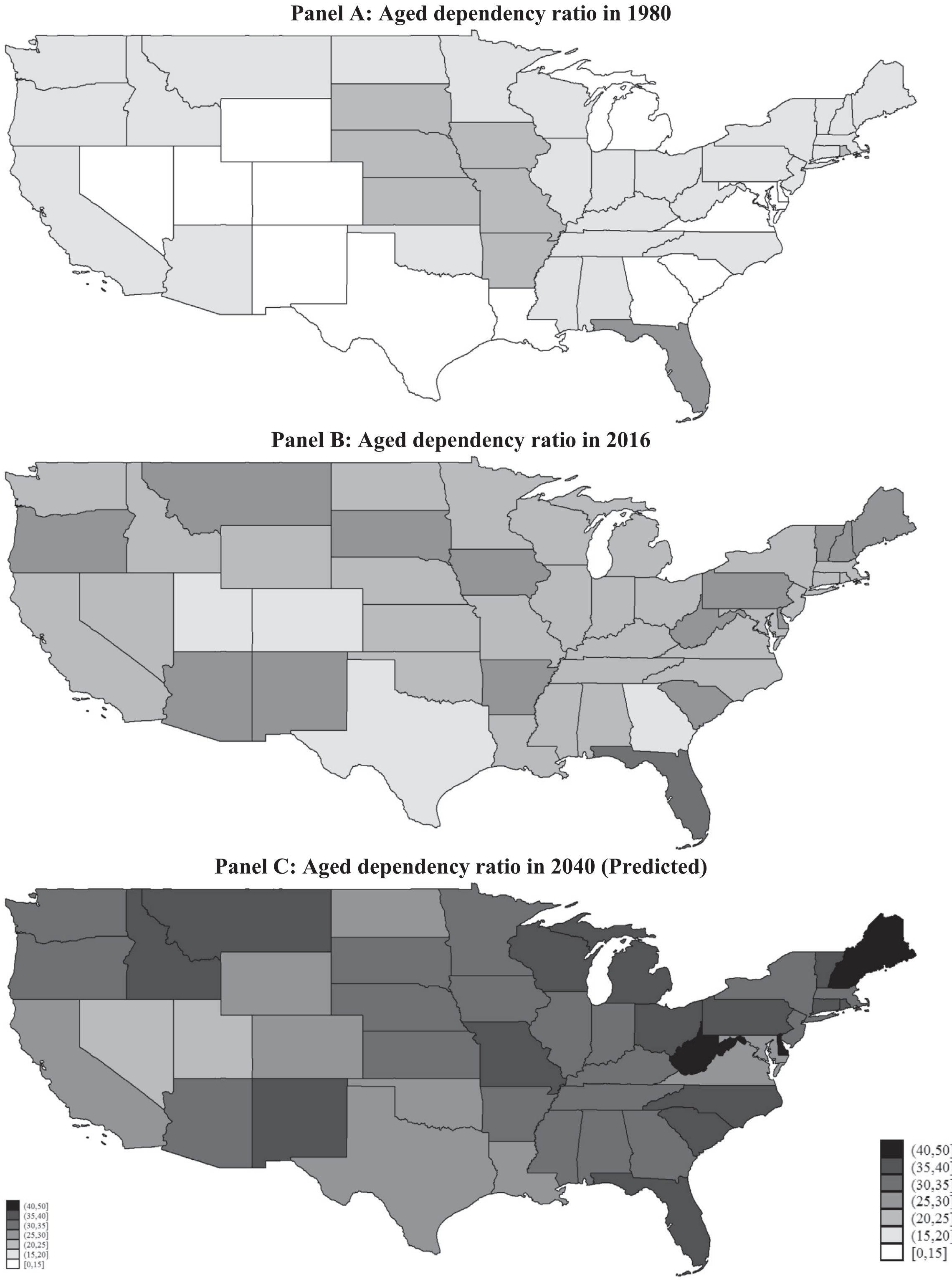

Fig. 2. Geographical Patterns of Population Aging Over Time. This figure plots the evolution of the aged dependency ratio, the ratio of the population above 65 to the population between the ages of 15 and 64–across states over time. The legends are shown in percentages. The projections are obtained from University of Virginia Weldon Cooper Center of Public Service.

and mortality patterns were entirely independent of government finance conditions, then OLS regressions would sufficiently identify the causal relationship between aging and bond market outcomes.

But government finance conditions can themselves shape the population age structure by affecting contemporaneous patterns of migration and mortality. State and local governments can use tax incentives (such as R&D tax credits or property tax deductions) to attract a target group of population. To the extent that the target population has a concentrated demographic profile, these government policies can alter the demographic composition of local residents. Furthermore, states with different age demographics may choose to issue more or fewer bonds based on the demand for

Table 3
Effect of Aging on Municipal Bond Yield: Baseline OLS Results. This table presents OLS and fixed effects estimates of the following regression equation: $Outcome_{it} = \beta_0 + \beta_1 Aging_{st} + \beta_2' State\ Characteristics_{st} + \beta_3' Bond\ Characteristics_{it} + \eta_s + \eta_t + \eta_m + \epsilon_{it}$. The outcome variables are listed at the top of each column. Yield Spread is the difference between yields of a municipal bond and a coupon and maturity-equivalent synthetic Treasury bond. Tax-Adjusted Yield Spread makes adjustments to yield spread calculations by accounting for muni tax benefit. Aging is the ratio of the population above 65 to the population between the ages of 15 and 64. Aging is standardized to have a mean of 0 and a standard deviation of 1. The rate of a variable is defined as the level of the variable divided by population and multiplied by 100. Net Migration Rate is migration inflow rate minus migration outflow rate. Personal Income Tax Rate is the top marginal rates. Competitive bid, Callable, Taxable and Credit Enhancement are dummy variables that take the value of 1 if the bond is sold through competitive bidding, callable, taxable, and credit enhanced, respectively. All columns include state, year and month fixed effects. Standard errors, adjusted for clustering at the state-year level, are reported in parentheses. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1) Raw Yield	(2) Yield Spread	(3) Tax-Adjusted Yield Spread
Aging	0.0647**	0.0650**	0.0663***
	(0.0325)	(0.0255)	(0.0254)
State Characteristics			
Log (Population)	−0.5905*	−0.8710***	−0.7344***
	(0.3132)	(0.2215)	(0.2344)
Net Migration Rate	0.0436	0.0063	0.0224
	(0.0348)	(0.0277)	(0.0283)
Mortality Rate < 65	−1.3965*	−1.9739***	−1.7959***
	(0.7262)	(0.6476)	(0.6186)
Mortality Rate 65+	−0.0701	−0.0332	−0.0446
	(0.1053)	(0.0792)	(0.0764)
Personal Income Tax Rate	0.0025	−0.0054	−0.0026
	(0.0105)	(0.0096)	(0.0092)
Bond Characteristics			
Log (Years to Maturity)	0.9138***	0.1790***	0.4485***
	(0.0306)	(0.0206)	(0.0201)
Log (Issue Size)	−0.0255***	−0.0190***	−0.0213***
	(0.0039)	(0.0033)	(0.0033)
Callable	0.2508***	0.1231***	0.1702***
	(0.0171)	(0.0171)	(0.0160)
Taxable	1.1054***	1.0696***	1.0790***
	(0.0364)	(0.0332)	(0.0338)
Competitive Bid	−0.1082***	−0.1465***	−0.1323***
	(0.0171)	(0.0165)	(0.0164)
Credit Enhancement	−0.1546***	−0.0958***	−0.1173***
	(0.0127)	(0.0122)	(0.0116)
Fixed Effects	State, Year, Month	State, Year, Month	State, Year, Month
Observations	102,854	102,854	102,854
Adjusted R^2	0.754	0.545	0.409

external capital to support that population or the anticipated ability to service debt claims with a lower tax base. Thus, a simple association between population aging and municipal finance is unlikely to represent the causal impact of population aging.

Two examples of biases that can result from the above endogeneity are as follows. First, if older individuals migrate to states with better financial and economic conditions, it would bias the OLS results against finding a positive relationship between aging and bond spread. This argument is supported by empirical evidence in Moretti and Wilson (2017), who find that top earners migrate to states with lower tax rates, and anecdotal evidence by SmartAsset (2018), who find that the states that have the largest influx of retirees are the states with low income, sales, and/or property taxes such as Florida, Georgia, Texas, Nevada, Tennessee, and Delaware.

Second, average life expectancy might be higher in states with better economic conditions that we cannot adequately control for, causing a downward bias in the OLS coefficients. If individuals with higher financial wealth live longer (Snyder and Evans, 2006; Chetty et al., 2016; Sachdeva, 2018), it would cause a positive relationship between state average life expectancy and economic conditions, hence a negative relationship between population aging and borrowing cost. Moreover, states with lower borrowing costs could spend more on improving local healthcare infrastructure and environmental quality, and consequently increase local residents' life expectancy. Hence, the omission of life expectancy as a control variable, resulting from the lack of state-level annual data, would bias the OLS results against finding that aging increases government borrowing cost.

3.3. Instrumental Variable: Historical birth rates

We use an instrumental variable approach to identify the causal relationship between aging and state bond spreads. The instrument is the sum of historical birth rates net of infant mortality in the 10-year period from t-65 to t-74 years in a state. We choose 74 years ago as a cutoff because the life expectancy at the start of our sample was, on average, 74 years. The instrument is mathematically expressed as:

$$Historical\,Birth\,Rate_{st} = \sum_{t'=t-74}^{t-65} \left(Birth\ Rate_{st'} - Infant\ Mortality_{st'}\right) \tag{4}$$

To serve as a valid instrument, historical birth rate must satisfy two conditions with respect to state aged dependency ratio: relevance and exclusion. The first stage result presented in Table 4, Column (1) shows that the instrument is strongly related to the aged dependency ratio—conditional on fixed effects and state and bond covariates, the first stage F-statistic is approximately 138. The instrument also generates economically meaningful variation in aging—the estimated elasticity of the aged dependency ratio with respect to historical birth rate is 0.48. Appendix Figure A1 shows a scatter plot of the residual aged dependency ratio against

Table 4

Effect of Aging on Municipal Bond Yield: IV Estimates using Birth Rates. This table presents IV estimates of the following system of equations: $Aging_{it} = \alpha_0 + \alpha_1 Historical\ Birth\ Rates_{st} + \alpha_2' State\ Characteristics_{st} + \alpha_3' Bond\ Characteristics_{it} + \lambda_s + \lambda_t + \lambda_m + v_{it}$, $Outcome_{it} = \beta_0 + \beta_1 \widehat{Aging_{st}} + \beta_2' State\ Characteristics_{st} + \beta_3' Bond\ Characteristics_{it} + \eta_s + \eta_t + \eta_m + \epsilon_{it}$. The dependent variables are listed at the top of each column. Column (1) is the first stage result, and Columns (2) – (4) are second stage results. Aging is the ratio of the population above 65 to the population between ages of 15 and 64. Historical Birth Rate is the sum of birth rates netting of infant mortality in the 10-year period from *t*-65 to *t*-74 years in a state. Aging and Historical Birth Rates are standardized to have a mean of 0 and a standard deviation of 1. Yield Spread is the difference between yields of a municipal bond and a coupon and maturity-equivalent synthetic Treasury bond. Tax-Adjusted Yield Spread makes adjustments to yield spread calculations by accounting for muni tax benefit. The rate of a variable is defined as the level of the variable divided by population and multiplied by 100. Net Migration Rate is migration inflow rate minus migration outflow rate. Personal and Corporate Income Tax Rate are the top marginal rates. Competitive bid, Callable, Taxable and Credit Enhancement are dummy variables that take the value of 1 if the bond is sold through competitive bidding, callable, taxable, and credit enhanced, respectively. Standard errors, adjusted for clustering at the state-year level, are reported in parentheses. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	First Stage	Second Stages		
	(1) Aging	(2) Raw Yield	(3) Yield Spread	(4) Tax-Adjusted Yield Spread
Historical Birth Rate	0.4801***			
	(0.0408)			
(Predicted) Aging		0.2476***	0.2270***	0.2328***
		(0.0727)	(0.0527)	(0.0531)
State Characteristics				
Log (Population)	−2.2122***	−0.5678*	−0.8918***	−0.7256***
	(0.4592)	(0.3244)	(0.1971)	(0.2138)
Net Migration Rate	−0.1257***	0.0695*	0.0249	0.0454
	(0.0406)	(0.0376)	(0.0276)	(0.0278)
Mortality Rate < 65	6.5446***	−3.1189***	−3.4644***	−3.2853***
	(0.8724)	(1.0736)	(0.8209)	(0.8164)
Mortality Rate 65+	−1.0060***	0.1831	0.2003**	0.1874**
	(0.0993)	(0.1364)	(0.0972)	(0.0936)
Personal Income Tax Rate	0.0097	−0.0025	−0.0092	−0.0060
	(0.0097)	(0.0111)	(0.0094)	(0.0092)
Bond Characteristics				
Log (Years to Maturity)	0.0014	0.9137***	0.1752***	0.4433***
	(0.0021)	(0.0306)	(0.0190)	(0.0192)
Log (Issue Size)	0.0021***	−0.0261***	−0.0176***	−0.0203***
	(0.0007)	(0.0039)	(0.0030)	(0.0030)
Callable	−0.0098***	0.2526***	0.1172***	0.1596***
	(0.0028)	(0.0172)	(0.0151)	(0.0136)
Taxable	0.0071*	1.1027***	1.0259***	1.0473***
	(0.0038)	(0.0364)	(0.0291)	(0.0291)
Competitive Bid	−0.0008	−0.1073***	−0.1401***	−0.1259***
	(0.0032)	(0.0171)	(0.0154)	(0.0154)
Credit Enhancement	0.0078*	−0.1569***	−0.0881***	−0.1087***
	(0.0040)	(0.0126)	(0.0108)	(0.0103)
Fixed Effects	State, Year, Month	State, Year, Month	State, Year, Month	State, Year, Month
Observations	102,584	102,584	102,584	102,584
Adjusted R^2	0.97	0.58	0.26	0.43

residual historical birth rate. The plot implements the Frisch-Waugh theorem to show visually how the unique variation in historical birth rate, net of state and time fixed effects and other covariates, predicts state aged dependency ratio.

We take a number of steps to verify that the first-stage relationship between historical birth rate and aged dependency ratio stems from economic, rather than statistical, reasons. One concern is that because the regression is at the bond-level, there are many repeated observational pairs of aged dependency ratio and historical birth rate within a state-year that could lead to over-inflated first-stage t-statistics. Clustering the standard errors by state-year mitigates this issue. Additionally, when we collapse our dataset to form a state-year panel, the instrument still has an F-statistic of 16.3 with only 934 state-year observations (see Table 5, Column (1)). A second concern is that the power of our instrument comes from a few outlier years instead of the entire sample period. To address this concern, we estimate the first stage regressions by 5-year time intervals, as shown in Appendix Table A2. The consistently positive and statistically significant first-stage relationship throughout all time intervals rules out the possibility that outliers in any given year drive our result. Moreover, birth rates are not especially persistent: the within-state standard deviation of historical birth rate is around 2.44%, comparable in magnitude to the between-state standard deviation of 2.93%.

Our identifying assumption is that decades-ago historical birth rates in a state affect local bond spreads only through their effect on the age structure of the population, after controlling for fixed effects and covariates. The assumption is plausible because any state-level factors that can affect both historical birth rates and state bond spreads today must persist for more than 65 years, and hence should be accounted for by state fixed effects. These factors might include, for example, state natural resources endowments and climate patterns that attract specific demographic groups, and persistent government institutional features, fiscal policies, or state economic conditions that affect debt issuing cost. Other factors that *stem* from age structure, such as political responses like state fiscal responsibility, may reflect a channel through which age structure impacts municipal financing costs. We examine several plausible channels in Section 4.

Columns (2)–(4) of Table 4 present results of the second stage estimations. The effect of instrumented aging on yield spreads is directionally consistent with the OLS results but the estimated magnitude is much larger. The coefficient on aging in Column (3) suggests that a one standard deviation increase in aging leads to a 23 basis points increase in debt spread, similar in magnitude to three notches rating downgrades. The effect is similar on tax-adjusted yield spread. In dollar terms, it is an additional $71 million in interest payment per year for an average state-year

Table 5
Effect of Projected Aging on Municipal Bond Yield: IV Estimates using Birth Rates. This table presents IV estimates of the following system of equations: $\text{Projected Aged Dependency Ratio}_{it} = \alpha_0 + \alpha_1 \text{Historical Birth Rates}_{st} + \alpha_2' \text{State Characteristics}_{st} + \alpha_3' \text{Bond Characteristics}_{it} + \lambda_s + \lambda_t + \lambda_m + \nu_{it}$, $\text{Outcome}_{it} = \beta_0 + \beta_1 \widehat{\text{Projected Aged Dependency Ratio}}_{it} + \beta_2' \text{State Characteristics}_{st} + \beta_3' \text{Bond Characteristics}_{it} + \eta_s + \eta_t + \eta_m + \epsilon_{it}$. The dependent variables are listed at the top of each column. Column (1) is the first stage result, and Columns (2) – (4) are second stage results. Projected Aged Dependency Ratio is the ratio of the population above 65 to the population between ages of 15 and 64 projected by the US Census. Historical Birth Rate is the sum of birth rates netting of infant mortality in the 10-year period from *t*-65 to *t*-74 years in a state. Aged Dependency Ratio and Historical Birth Rates are standardized to have a mean of 0 and a standard deviation of 1. Yield Spread is the difference between yields of a municipal bond and a coupon and maturity-equivalent synthetic Treasury bond. Tax-Adjusted Yield Spread makes adjustments to yield spread calculations by accounting for muni tax benefit. The rate of a variable is defined as the level of the variable divided by population and multiplied by 100. Net Migration Rate is migration inflow rate minus migration outflow rate. Personal and Corporate Income Tax Rate are the top marginal rates. Competitive bid, Callable, Taxable and Credit Enhancement are dummy variables that take the value of 1 if the bond is sold through competitive bidding, callable, taxable, and credit enhanced, respectively. Standard errors, adjusted for clustering at the state-year level, are reported in parentheses. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	First Stage	Second Stage		
	(1) Aging	(2) Raw Yield	(3) Yield Spread	(4) Tax-Adjusted Yield Spread
Historical Birth Rate	0.3552***			
	(0.0178)			
(Predicted) Projected Aged Dependency Ratio		0.2133***	0.3742***	0.2952***
		(0.0472)	(0.0343)	(0.0237)
State Characteristics				
Log (Population)	1.0345***	−1.2681***	−1.6388***	−1.4852***
	(0.2158)	(0.2350)	(0.2282)	(0.2060)
Net Migration Rate	0.0795***	−0.0112	−0.0764***	−0.0481*
	(0.0259)	(0.0305)	(0.0281)	(0.0249)
Mortality Rate < 65	−0.6769	−0.4063	−1.7875**	−1.3108**
	(0.5918)	(0.6814)	(0.6950)	(0.6008)
Mortality Rate 65+	0.3377***	−0.2179**	−0.2354***	−0.2301***
	(0.0649)	(0.0855)	(0.0749)	(0.0627)
Personal Income Tax Rate	−0.0327***	0.0192**	0.0032	0.0085
	(0.0072)	(0.0086)	(0.0097)	(0.0082)
Bond Characteristics				
Log (Years to Maturity)	0.3423***	0.6002***	−0.1850***	0.1227***
	(0.0235)	(0.0363)	(0.0287)	(0.0205)
Log (Issue Size)	0.0207***	−0.0389***	−0.0418***	−0.0405***
	(0.0022)	(0.0037)	(0.0031)	(0.0026)
Callable	0.1849***	0.1543***	−0.0011	0.0495***
	(0.0126)	(0.0182)	(0.0157)	(0.0119)
Taxable	0.0041	1.0011***	1.0003***	1.0162***
	(0.0116)	(0.0347)	(0.0321)	(0.0294)
Competitive Bid	0.0377***	−0.1486***	−0.1832***	−0.1696***
	(0.0065)	(0.0089)	(0.0083)	(0.0073)
Credit Enhancement	−0.0227***	−0.1043***	−0.0518***	−0.0716***
	(0.0067)	(0.0096)	(0.0093)	(0.0076)
Fixed Effects	State, Year, Month	State, Year, Month	State, Year, Month	State, Year, Month
Observations	65,198	65,198	65,198	65,198
R2	0.8489	0.5655	0.2459	0.4251

aggregate bond issuance. The increase in the magnitude of the effects from OLS to IV estimation suggests that the endogeneity issues discussed in the previous section attenuate the OLS coefficients. In Appendix Table A3, we follow the suggestions of Solon et al. (2015) and use weighted regressions to correct for the sampling bias stemming from state differential frequency of bond issuance. We weight each observation by the inverse of the number of bond issuances in a state-year and repeat the instrumental variable analysis. The results confirm the findings presented in Table 4.

Because our sample period spans the Great Recession, it is worth thinking carefully about whether and how it can affect our estimates. If state exposure to the Great Recession happens to be systematically correlated with long-ago birth rates, then this correlation could generate a spurious relationship between predicted Aging and bond yields. However, we find that states with high historical birth rates are generally not the states that were affected heavily by the Great Recession. When we sort states based on their levels of historical birth rates and Great Recession exposure (measured using house price change from 2006 to 2009), states that are in the top quintiles of both distributions have minimal overlap. The only overlapping state is Arizona, and dropping Arizona from our sample does not alter our estimates meaningfully. We also identify the states that have both large estimated aging effects and exposure to the Great Recession (Figure A2). These states could have a large influence on our IV estimates if the alternative story is true. We exclude these states and re-run the IV regressions (Table A4), and obtain coefficient estimates that are similar in magnitudes (i.e., a 20–24 basis point effect).

Contemporaneous state tax rates may not sufficiently control local government tax structures. To address this concern, we show that our results are robust to further controls of states' tax structure by controlling in turn for three-, five-, and ten-year lagged or average state historical personal and corporate income tax rates in the appendix (Table A12). Related to tax structures, one might also expect that contemporaneous changes in state institutional feature (such as voter approval requirements for tax increases or tax and expenditure limits) would affect our estimated effects (Jordan and Hoffman, 2009; Pathak, 2017). We control for these in changes in several ways (for example, excluding states that had these changes from our sample, or control for an indicator variable that takes a value of one after these changes occur), and conclude that they are not driving our results.

3.4. Interpreting the difference between OLS and IV estimates

In this section, we investigate some of the economic reasons behind the coefficient change from the OLS to IV estimates. Panel A and Panel B of Fig. 3 plot the relationship between a state's aged

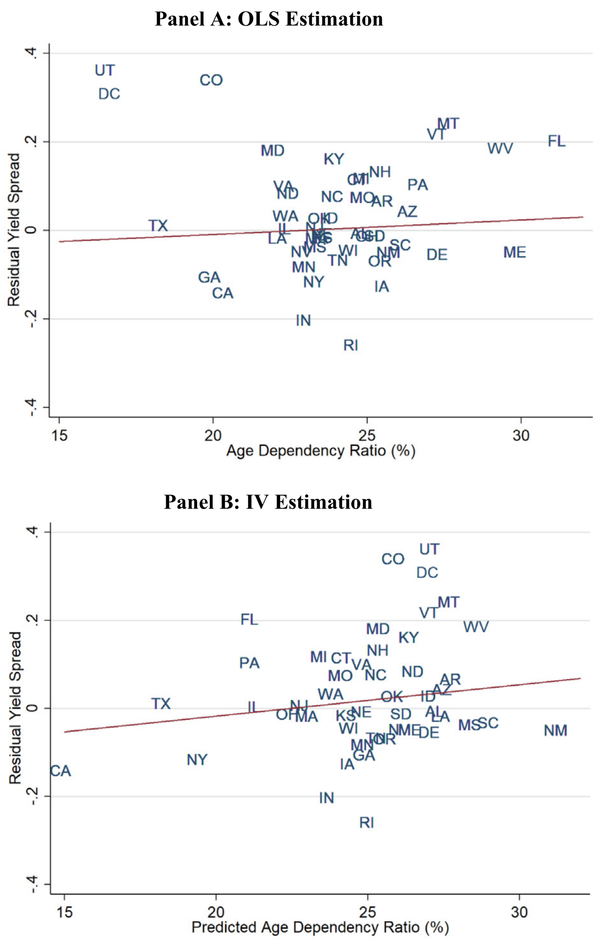

Fig. 3. Residual Plots of the Relationship between Aging and Yield Spread. Panel A of this figure shows a scatter plot of average state residual yield spread against aged dependency ratio. Panel B shows a scatter plot of average state residual yield spread against aged dependency ratio *predicted* by historical birth rate. Yield spread is residualized with respect to all state and bond characteristics, as well as state, year and month fixed effects. Aged Dependency Ratio is the ratio of the population above 65 to the population between the ages of 15 and 64. Predicted Aged Dependency Ratio is the fitted value of the first stage IV regression. Historical Birth Rate is the sum of birth rates netting of infant mortality in the 10-year period from t-65 to t-74 years in a state. The figure only plots the cross section of data in 2016 for better visualization of the positions of states. Comparing the location of states on the horizontal axis across panel A and B provides evidence on how the instrumental variables are removing the variation in state population aging due to endogenous migration.

dependency ratio and the average residual yield spread in the OLS and IV regressions, respectively. We compute the state average residual yield using the following procedure. First, we regress yield spreads on all control variables and fixed effects in the regressions in Table 4 and calculate the residuals from the regression. Second, we take the average of the residual yield spreads by state and year and plot the cross section of data in the most recent year, 2016, for better visualization of the positions of states. In Panel B, we also compute the predicted aged dependency ratio by calculating the fitted value of the first stage regression reported in Column (1) of Table 4 and plot the residual yield spreads against the predicted aged dependency ratio.

Comparing the location of states along the horizontal axis in Panel A and B of Fig. 3 provides suggestive evidence on how the instrumental variable is removing the variation in state population aging due to endogenous migration. For example, in Panel A, Florida is located in the right-most position on the graph because it has the highest degree of population aging in 2016. In Panel B, however, Florida moves on the horizontal axis from more than 30% to about 20%. This horizontal movement suggests that if Florida *only* had population that was born 65 years ago in Florida, its current aged dependency ratio would have been much lower than it is today. This result is consistent with a recent survey conducted by SmartAsset, which reveals that Florida is the top destination for retiree relocation due to low income tax, low inheritance tax, high property tax exemptions, and pleasant weather (SmartAsset, 2018). Migration data from IRS also shows that the annual net migration rate in Florida has been consistently positive except for during the financial crisis (see Fig. 4).

On the other hand, in states such as California, young people are moving out due to high cost of living. A recent article published by California Legislative Analyst's Office describes that wealthier people are moving into California whereas young and less-educated people are moving out to states such as Texas, Arizona, and Nevada due to unaffordable living expenses (California Legislative Analyst's Office, 2018). These migration patterns contribute to a more severe population aging issue than predicted by the state's historical birth rates, consistent with the leftward shift of California on the horizontal axis from Panel A compared to Panel B in Fig. 3. Panel A of Fig. 3 shows that California's current aged dependency ratio is around 21%. Panel B suggests that if California *only* had the population that was born there 65 years ago, its current aged dependency ratio would have only been around 15%.

The examples of Florida and California show that endogenous migration patterns, if not removed by the instrumental variable, would attenuate the OLS coefficient estimates. From the perspective of estimating a causal effect, this attenuation bias is a shortcoming of the OLS framework. From the perspective of evaluating policy choices, however, this attenuation is crucial. The IV approach isolates one and only one economic channel (the aging of existing residents) through which population changes affect public finance. The OLS approach, by contrast, detects equilibrium outcomes that include other offsetting mechanisms such as migration of retirees and young talent and states' fiscal policies that induce or stanch such migration. Thus, we interpret the IV results as a ceteris paribus outcome: what would happen to states' finances in the absence of offsetting policies. The OLS results, in turn, show the net effect aging has on states' finances after the states' policies are included in the estimate. It is not surprising, then, that the IV results are larger in magnitude than the OLS results. And furthermore it is not surprising that the OLS results are significant, perhaps due to decreasing marginal returns of states' policies that might influence the population age.

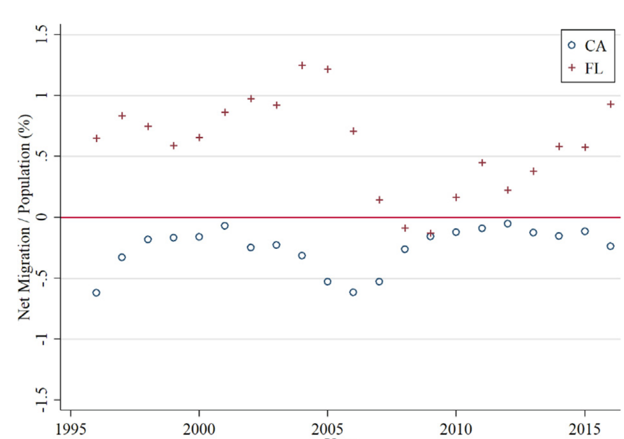

Fig. 4. Migration Rates for California and Florida. This figure plots the net migration rates (per 100 population) for California and Florida over time between 1996 and 2016. Net migration is defined as migration inflow minus migration outflow.

3.5. Projected population aging

Conceptually, both current and future aging should matter for bond spreads, as they both affect a government's accumulation of tax revenues during the life of a bond, and therefore its ability to pay back a bond's principal payment and interests. Below, we first describe tests we run that use forecasts of future agedness, then we offer some reasons why at-issuance agedness may be a preferable measure.

We collect data on future population age forecasts from Census. The most recent of these forecasts is from 2004, and is based on the 2000 Census. These state-level forecasts go out to 2030. Based on the Census forecast data, we create a forecast of aged dependency ratio based on each bond's maturity. For example, for a bond issued in 2001 with ten years maturity, we use the forecasted aged dependency ratio in year 2011, which is computed as the fraction of population above 65 in 2011 divided by the fraction of working age population in 2011. Similarly, a 20-year bond issued in 2001 would have a forecast aged dependency ratio computed as the fraction of population above 65 in 2021 divided by the fraction of working age population in 2021, and so on. We also collect historical birth rates and infant mortality rates for each state from 1952 to 1960 from the CDC's annual Vital Statistics of the United States publications to construct a similar instrument for the forecast aged dependency ratio.

In Table 5 we present IV tests that use the forecast aged dependency ratio. Similar to the tests described in Section 3.3, we run two-stage least square regressions to gauge the relationship between future aged dependency ratio and bond spreads, and report the results in Table 5. The first-stage coefficients confirm a strong instrument. Although the second-stage coefficients are larger in magnitude than those using at-issuance predicted aged dependency ratio, two of the three second stage coefficients are within the confidence intervals of the corresponding coefficients in Table 4.

Although using forecasts of the aged dependency ratio at the bond's maturity has intuitive appeal, there are some important limitations to doing so. The first limitation is data availability. The sample size in the IV regression using the forecasted aged dependency ratio shrinks by about 37% compared to the sample in Table 4. Two reasons drive this sample size reduction. First, because the projection is only till 2030, we drop all bonds that mature after 2030. Second, birth rates data (used to construct the IV) are missing for the years 1961–1965, because the CDC did not report consistent state-level birth rate estimates for these years, and so we also drop all observations for which the instrument requires an observation of birth rate from these years (about 17% of the sample).

The second limitation is the accuracy of the forecasts. The Census conducted its most recent state-level population age forecasts in 2004 based on 2000 data. To check whether these forecasts are reasonably accurate, we compare the 2004 forecast of the aged dependency ratio in 2019 to the recently published state-level realization of the aged dependency ratio in 2019. We find that the error percentage is 5.4% on average and can be as high as 23%. The projection errors may accumulate and grow larger for later years such as 2030.

Nonetheless, we can partially validate the assumption that current aged dependency ratio might be an adequate proxy for that unmeasurable anticipation by market participants. We correlate state-level current aged dependency ratio measured in 2016 (the last year of our sample) with forecast aged dependency ratio for 2025 and 2030 (the most distant forecast in the Census data). The correlations are 0.90 and 0.81, respectively. Additionally, when we rank states based on their aged dependency ratio in 2016 and 2030, respectively, eight of the states ranked bottom ten in 2016 still rank bottom ten in 2030, and six of the states ranked top ten in 2016 still rank top ten in 2030.

Thus, we conclude that: 1) current aged dependency ratio is a reasonable proxy for future aged dependency ratio; 2) future aged dependency ratio (or at least forecasts of it) have a slightly stronger relation to municipal bond yield spreads than current aged dependency ratio, and that our results based on current aged dependency ratio probably understate the true effect of aging on municipal financing.

3.6. Differential exposure to the impact of aging

Population aging will affect some bonds more than others, such as bonds from issuers or lower credit quality and longer maturity bonds. In this section, we examine the heterogeneous effect of aging on public financing cost. These tests support the causal interpretation of our IV results, by limiting the scope of unobserved confounding covariates to explain our results. We use bond ratings of AA or below as a proxy for lower government credit quality, and bond maturity horizon of above 15 years to categorize long-term bonds. These sample splits have 78.1% of bonds in the high-quality category and 21.9% in the low-quality category, and 50.3% in the long maturity and 49.7% in the short maturity categories, respectively.

Table 6 presents instrumental variable results for the cross-sectional analysis. Consistent with our hypotheses, we find that the effect of population aging on government borrowing costs is much larger and more statistically significant for bonds with lower credit quality. For high quality bonds rated above AA, Columns (1) through (3) show that the effect of aging on bond spread is between 6–16 basis points and are not statistically significant. For bonds rated AA or below, however, the estimates of the effect are about 19–20 basis points larger, and statistically significant at the 5% level. Our conclusions do not change if we instead use A + or below as the cutoff for lower credit quality. The heterogeneous impact of population aging on high and lower credit quality governments is consistent with Novy-Marx and Rauh (2012), who find that the "sovereign default channel" in the municipal market only affects low credit quality governments. Because states may assist with the debt payments if a local government defaults, we also conduct a version of the tests using state government credit ratings, rather than bond-level ratings (Gao et al., 2019). We show these results in Appendix Table A6. Our inferences remain unchanged.

Columns (4) – (6) of Table 6 show that the effect of population aging on yields of long-term bonds is almost twice as large as the effect for short term bonds. A one standard deviation increase in the state aged dependency ratio leads to an 18–19 basis points increase in state and local bond issue spreads, and the effect is an additional 16–17 basis points increase for long term bonds. This effect is consistent with investors requiring a higher premium to compensate for longer exposures to the risks brought by population aging. The result is robust to instead using 10 or 20 years as cutoffs for categorizing long-term bonds.

Do issuers respond to an aging population by altering the maturities of the bonds they issue? We test this hypothesis in Appendix Table A10. We find that bond maturity at issuance does not change as a state's population ages. One dimension that does appear to change is the coupon rate for the bonds: aged dependency ratio is strongly related to higher coupons. This increase is consistent with our main finding that agedness relates to higher yield spreads because coupons are a key component of the returns on the bonds, especially because most municipal bonds are issued at a price very close to par value.

Table 6
Debt Maturity, Credit Quality, and the Heterogeneous Effect of Aging. This table presents 2SLS IV estimates. The dependent variables are listed at the top of each column. Yield Spread is the difference between yields of a municipal bond and a coupon and maturity-equivalent synthetic Treasury bond. Tax-Adjusted Yield Spread makes adjustments to yield spread calculations by accounting for muni tax benefit. Aging is the ratio of the population above 65 to the population between the ages of 15 and 64. Rated AA or Below is an indicator that equals one if a bond's S&P credit rating is AA or below. Long Term Bonds is an indicator that equals one if the bond maturity is longer than 15 years. Aging is standardized to have a mean of 0 and a standard deviation of 1. Control variables include the natural logarithm of population, net migration rate, mortality rate, personal income tax rates, bond years to maturity, and indicators for whether the bond is callable, taxable, credit enhanced, and sold through competitive bidding. The types of fixed effects included in the regression are listed towards the bottom of each column. Standard errors, adjusted for clustering at the state-year level, are reported in parentheses. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	Rating Split			**Maturity Split**		
	(1) Raw Yield	(2) Yield Spread	(3) Tax-Adjusted Yield Spread	(4) Raw Yield	(5) Yield Spread	(6) Tax-Adjusted Yield Spread
(Predicted) Aging X Rated AA or Below	0.1920**	0.2030**	0.1913**			
	(0.0838)	(0.0836)	(0.0783)			
(Predicted) Aging X Long Term Bonds				0.1750***	0.1624***	0.1676***
				(0.0093)	(0.0070)	(0.0065)
(Predicted) Aging	0.1636	0.0657	0.1014	0.1921***	0.1842***	0.1886***
	(0.1065)	(0.1000)	(0.0959)	(0.0684)	(0.0504)	(0.0507)
State and Bond Characteristics Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects	State, Year, Month	State, Year, Month	State, Year, Month	State, Year, Month	State, Year, Month	State, Year, Month
Observations	61,068	61,068	61,068	102,854	102,854	102,854
Adjusted R^2	0.639	0.316	0.498	0.599	0.295	0.468

3.7. Placebo tests using revenue bonds

In previous sections we limit our analysis to the sample of General Obligation municipal bonds, which are secured by the general revenue of the issuing municipality. Revenue bonds, on the other hand, are secured by fees collected from specific projects, such as building a new water plant, a tollway, or an airport. Because the cash flows from these projects may not be directly related to aging effects we discussed, revenue bonds could serve as a natural placebo group.

To this end, we collect data on the bond characteristics for over 60,000 municipal revenue bonds issued by state and local governments during the same sample period. We estimate the effects of aging on the yield spreads of these bonds and report the results in the Appendix Table A7. In Panel A, we use the entire sample of revenue bonds. In Panel B, we use the subsample of utility-related revenue bonds. Because people from all age groups rely on water, wastewater, and electricity services, utility-related bonds may be the most immune to the effects of aging. In both panels, the coefficient estimates on the predicted aged dependency ratio are small and statistically indistinguishable from zero.

3.8. Gross Spread

The main results of the paper show an overall negative impact of population aging on the cost of public finance, consistent with population aging being a priced risk factor for municipal bonds. However, theoretical and anecdotal evidence also suggests that an aging population could *increase* demand for safe and tax-exempt assets such as municipal bonds. For example, life-cycle portfolio choice models argue that investors decrease financial portfolio risk as they age (e.g. Jagannathan and Kocherlakota, 1996; Bodie and Crane, 1997; Back et al., 2019). Consistent with implications of these models, financial advisers often recommend that retirees increase municipal bond holdings due to their risk features and tax benefits.[11]

We test this demand channel by examining an outcome that is not directly affected by default risk: the fees that investment banks charge to underwrite the placement of the bonds. Gross spread, typically expressed as a percent of the offering amount, is the compensation the investment banks intermediating the offering receives for helping an issuer sell a security to investors. Intuitively, the more difficult it is for the underwriting syndicate to sell the security to investors, the more compensation they should receive (Lee et al., 1996; Butler et al., 2005). When a bond is issued by a municipality that experiences rapid aging, and therefore have higher default risk, the bond could be less popular among investors, making it more difficult for the underwriters to place the bond. Therefore, the underwriters could charge a higher spread. Alternatively, if population aging creates increased demand for newly issued municipal bonds, that demand might reflect in the ease with which underwriters can sell the bonds to investors.

In Table 7 we present evidence consistent with the rising demand channel. Our hypothesis is that if underwriters anticipate such demand-side effects, they might decrease the gross spreads they charge the issuers ex ante, because placing the bond becomes easier.

Around 47% of bonds have non-missing data for the underwriter-related variables. Our instrument is relevant with a first-stage F-statistic around 120. Column (2) estimates show that a one standard deviation increase in the aged dependency ratio is associated with a 22 basis points (0.4 standard deviation) reduction in underwriter gross spread. The effect is similar when we control for lead manager fixed effects, as shown in Column (4).

4. Mechanisms

4.1. Tax revenue

We now investigate the channels through which aging impacts municipal bond yield spreads. We develop three hypotheses based on existing theoretical and empirical literature. Our first hypothesis is that aging reduces state tax revenue, the primary source of funding for municipal bond payments, and therefore increases municipal bond default risks. If an older population can lead to reduced labor productivity and a smaller labor force, it would reduce the overall size of the economy, which is the ultimate tax base for governments (Hansen, 1939; Feyrer, 2007; Maestas et al., 2016). Empirical evidence also suggests that workers' earnings peak in their 40 s (Murphy and Welch, 1990), which implies a negative association between aged dependency ratio and income tax revenue.

[11] For example, see https://www.thebalance.com/municipal-bonds-investing-for-income-benefits-357924 and https://money.cnn.com/retirement/guide/investing_bonds.moneymag/index7.htm.

Table 7

Effect of Aging on Municipal Bond Underwriter Gross Spread. This table presents IV estimates of the following system of equations: $\boldsymbol{Aging_{it}} = \alpha_0 + \alpha_1 \boldsymbol{Historical\ Birth\ Rates_{st}} + \alpha_2' \boldsymbol{State\ Characteristics_{st}} + \alpha_3' \boldsymbol{Bond\ Characteristics_{it}} + \lambda_s + \lambda_t + \lambda_m + \nu_{it}$, $\boldsymbol{Outcome_{it}} = \beta_0 + \beta_1 \widehat{\boldsymbol{Aging}}_{st} + \beta_2' \boldsymbol{State\ Characteristics_{st}} + \beta_3' \boldsymbol{Bond\ Characteristics_{it}} + \eta_s + \eta_t + \eta_m + \epsilon_{it}$. The dependent variables is the municipal bond underwriter gross spread in terms of basis points. Columns (1) and (3) are first stage results, and Columns (2) and (4) are second stage results. Columns (1) and (2) include state, year, and month fixed effects. Columns (3) and (4) include lead manager fixed effects in addition. Aging is the ratio of the population above 65 to the population between ages of 15 and 64. Historical Birth Rate is the sum of birth rates netting of infant mortality in the 10-year period from t-65 to t-74 years in a state. Aging and Historical Birth Rates are standardized to have a mean of 0 and a standard deviation of 1. Net Migration Rate is the percentage migration inflow rate minus percentage migration outflow rate. Personal and Corporate Income Tax Rate are the top marginal rates. Competitive bid, Callable, Taxable and Credit Enhancement are dummy variables that take the value of 1 if the bond is sold through competitive bidding, callable, taxable, and credit enhanced, respectively. Standard errors, adjusted for clustering at the state-year level, are reported in parentheses. $***$, $**$, and $*$ represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	Dependent Variable: Underwriter Gross Spread (Basis Points)			
	Without Lead Manager Fixed Effects		With Lead Manager Fixed Effects	
	First Stage	*Second Stage*	*First Stage*	*Second Stage*
	(1)	(2)	(3)	(4)
Historical Birth Rate	0.4852***		0.4513***	
	(0.0442)		(0.0399)	
(Predicted) Aging		−22.1207***		−23.0683***
		(5.3002)		(5.8262)
State Characteristics				
Log (Population)	−2.1563***	41.4762**	−2.0718***	0.5002
	(0.4544)	(19.1410)	(0.4209)	(17.7548)
Net Migration Rate	−0.0830**	−6.4118***	−0.0753**	−6.7276***
	(0.0372)	(2.4289)	(0.0349)	(2.2304)
Mortality Rate < 65	7.7364***	228.3888***	7.6567***	251.4780***
	(0.8134)	(75.1222)	(0.7308)	(72.1044)
Mortality Rate 65+	−1.1009***	−12.8614	−1.0502***	−11.6421
	(0.1089)	(9.7272)	(0.1002)	(9.1912)
Personal Income Tax Rate	−0.0093	−1.3148*	−0.0050	−0.8621
	(0.0095)	(0.6851)	(0.0089)	(0.6381)
Bond Characteristics				
Log (Years to Maturity)	−0.0032	25.2610***	−0.0026	25.1472***
	(0.0026)	(1.3483)	(0.0022)	(1.2256)
Log (Issue Size)	0.0018**	−17.7124***	0.0007	−16.1288***
	(0.0008)	(0.5578)	(0.0008)	(0.4455)
Callable	−0.0056	3.2821***	−0.0033	0.6858
	(0.0037)	(1.0135)	(0.0032)	(0.9375)
Taxable	0.0093**	−5.4043***	0.0064	−4.8443***
	(0.0044)	(1.1534)	(0.0039)	(1.0301)
Competitive Bid	0.0022	0.8852	0.0035	8.0021**
	(0.0039)	(3.9257)	(0.0037)	(3.7654)
Credit Enhancement	0.0124**	−2.0362**	0.0158***	−1.0070
	(0.0051)	(0.9140)	(0.0043)	(0.8501)
Fixed Effects	State, Year, Month	State, Year, Month	State, Year, Month, Lead Manager	State, Year, Month, Lead Manager
Observations	48,138	48,138	47,995	47,995
R-squared	0.40	0.23	0.98	0.19

We test this tax revenue hypothesis by running instrumental variable regressions of the measures of tax revenue on state aged dependency ratio. Because tax revenues do not vary at the bond level, we aggregate the variables at state level and run state panel regressions instead of bond level regressions. We cluster standard errors at the state level. The first stage F-statistic of 16.3 presented in Column (1) of Table 8 verifies the relevance of the instrument in the panel dataset.

We present the second stage regressions in Columns (2) – (4). We first test whether aging significantly impacts state and local tax revenue collections. The coefficient estimates in Column (2) suggest that a one standard deviation change in aged dependency ratio decreases personal income tax revenue per capita by 10.9%, supporting our first hypothesis. In Column (3), we use states with no personal income tax as a placebo and, as expected, find no reduction in personal income tax revenue. In Column (4), we find that the effect is slightly larger when we exclude zero income tax states.

These results contrast with Acemoglu and Restrepo (2017), who show that faster aging promotes technology adoption and therefore increases GDP growth in a cross-country setting. Our empirical design utilizes intra-country variation, where technology development should be much more homogeneous. Therefore, if decreasing labor productivity and increasing machine efficiency are competing forces that affect the size of the economy, in our setting the former is likely to dominate the latter.

In untabulated regressions, we find no evidence of changes in sales and property tax revenue as a result of population aging. Although older adults have an increased propensity to consume, they are less likely to contribute to the tax base because medical goods and senior-owned homes frequently receive tax exemptions (e.g., Sjoquist et al., 2007; Felix and Watkins, 2013).

Next, we conduct a deeper exploration of whether and how a state's tax structure—income tax compared to other revenue sources—matters for the effect of aging on bond spreads. We calculate the proportion of state tax revenue that is income tax and split the sample at the median of that proportion (a median state has about 25% reliance on income tax revenues). We find that tax structure matters in the way one might expect: the effect is larger for states that are more reliant on income tax (a 28 basis point effect) than those below the median (a 10 basis point effect). We repeat this exercise using the income tax proportion in 1995, the

Table 8
Effect of Aging on State and Local Government Income Tax Revenue. This table presents IV estimates of the following system of equations: $Aging_{st} = \alpha_0 + \alpha_1 Birth\ Rates_{st} + \alpha_2{}' State\ Characteristics_{st} + \lambda_s + \lambda_t + v_{st}$,. $Outcome_{st} = \beta_0 + \beta_1 \widehat{Aging}_{st} + \beta_2' State\ Characteristics_{st} + \eta_s + \eta_t + \epsilon_{st}$. The dependent variables are listed at the top of each column. Column (1) is first stage results, and Columns (2) – (6) are second stage results. Aging is the ratio of the population above 65 to the population between the ages of 15 and 64. Historical Rate is the sum of birth rates from 65 to 74 years ago. Aging and Historical Birth Rate are standardized to have a mean of 0 and a standard deviation of 1. Personal Income Tax Revenue Per Capita is state total personal tax revenue receipts divided by population. In Column (2), the sample contains all states. In Column (3), the sample is only states with zero personal income tax rate, FL, NH, NV,SD,TN, TX, WA, and WY. In Column (4), the sample excludes states with zero personal income tax rate. Net Migration Rate is migration inflow minus migration outflow per 100 population. Personal and Corporate Income Tax Rate are the top marginal tax rates. State and year fixed effects are included in all regressions. Standard errors, adjusted for clustering at the state level, are reported in parentheses. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	First Stage	*Second Stages*		
	Aging	**Log (Personal Income Tax Revenue Per Capita)**		
		All States	Tax Rate = 0 States (Placebo)	Tax Rate > 0 States
	(1)	(2)	(3)	(4)
Historical Birth Rate	0.5517***			
	(0.1347)			
(Predicted) Aging		−0.1094**	0.0229	−0.1127*
		(0.0542)	(0.0549)	(0.0598)
<u>*State Characteristics*</u>				
Net Migration Rate (%)	−0.1949**	0.0429	0.0066	0.0583
	(0.0865)	(0.0316)	(0.0201)	(0.0401)
Log (Population)	−1.3620	−0.5172**	−0.0116	−0.4585*
	(1.1004)	(0.2246)	(0.4411)	(0.2494)
Personal Income Tax Rate	0.0118	0.0556***	N/A	0.0559***
	(0.0483)	(0.0086)		(0.0087)
Corporate Income Tax Rate	0.0152	−0.0101	0.0078	−0.0096
	(0.0212)	(0.0124)	(0.0097)	(0.0119)
Fixed Effects	State, Year	State, Year	State, Year	State, Year
Observations	934	934	133	801
Adjusted R^2	0.94	0.24	−0.01	0.27

year before our sample starts, which is more likely to be exogenous than the time-varying proportion. We find a quantitatively similar result. We report these results in Appendix Table A11.

4.2. Pension and healthcare liability

Our second and third hypotheses are that aging raises state borrowing costs through increasing unfunded pension obligations and retiree healthcare liabilities, respectively. Given the protections that state constitutions offer to the pensions of public employees, accrued public pension promises are generally at least as senior as state General Obligation bonds. Indeed, many states have either constitutional guarantees of pension promise or statutory laws protecting them, and events from past municipal debt crises suggest that pension claims are usually preserved even when the positions of bondholders are impaired (Brown and Wilcox, 2009). As a result, retiree payments can crowd out bondholder payments in the event of a fiscal crisis, and therefore increase the default risk of municipal bonds.

We explore the cross-state difference in the extent to which public pensions are legally protected to test for the pension liability hypothesis. There are two general approaches through which state constitutions offer protections for public pensions. States such as Illinois and New York have constitutional provisions that explicitly prevent the state from reducing benefits that public employees expected at the time of employment. Other states such as Alabama and California protect pensions under contract provisions, which prohibit a state from passing any law that impairs existing public or private contracts. In states with neither explicit nor contract-based constitutional pension protection, state officials have relatively more freedom to adjust future pension benefits (Brown and Wilcox, 2009; Munnel and Quinby, 2012).

We follow the classification of Munnel and Quinby (2012) to define states with constitutional protections for public pension obligations (details can be found in Appendix Table A5). We regress bond spreads on the interactions of the aged dependency ratio and indicators for whether a state has constitutional protection for pension liabilities. We instrument for the aged dependency ratio using historical birth rates and separately instrument for the interaction term using the interaction of historical birth rates and the indicator for constitutional protection.

We present our results in Table 9. Columns (1) through (3) show that among states without any of the two types of constitutional protections for public pensions, a one standard deviation increase in the aged dependency ratio only leads to an 18–19 basis points increase in municipal bond spread. However, in states with constitutional pension protections, the effect is an additional 19–21 basis points increase in bond spreads. The results are robust to using a narrower definition of constitutionally protected states, i.e., states with only explicit provisions guarantee pension benefits. These findings further confirm the importance of the pension liability channel in explaining the overall effect of aging on public financing costs and highlight the role state political economy plays in influencing local government access to credit.

In Table 10, we further examine state hospital and health spending. Column (1) shows that a one standard deviation increase in the state aged dependency ratio is associated with a 20% increase in state and local hospital spending per capita, which is spending on the construction, acquisition, maintenance, and operation of hospital facilities, provision of hospital care, and support of public or private hospitals. In Column (2), however, we find a statistically insignificant increase in the general health spending per capita, which is spending on public health administration, research, and education, immunization clinics, environmental health activities such as air and water pollution control, and other general public health activities such as mosquito abatement. This dichotomy suggests that an older population increases the burden of state and local governments to invest in hospital infrastructure and operations, but not general preventative measures targeting the overall population like immunization and pollution control.

Using data on state pension and OPEB liabilities, we find further support for our second and third hypotheses. In Columns (3) – (4), we run instrumental variable regressions of state pension liability ratio and OPEB funding ratio on aged dependency ratio. Similar to

Table 9
State Pension Constitutional Protection and the Heterogeneous Effect of Aging. This table presents 2SLS IV estimates. The dependent variables are listed at the top of each column. Yield Spread is the difference between yields of a municipal bond and a coupon and maturity-equivalent synthetic Treasury bond. Tax-Adjusted Yield Spread makes adjustments to yield spread calculations by accounting for muni tax benefit. Aging is the ratio of the population above 65 to the population between the ages of 15 and 64. Constitutional Protection is an indicator that equals one if a state has provisions protecting employee pension liabilities in its constitution. Aging is standardized to have a mean of 0 and a standard deviation of 1. The instrument for Aging, Historical Birth Rate, is the sum of birth rates netting of infant mortality in the 10-year period from *t*-65 to *t*-74 years in a state. Control variables include the natural logarithm of population, net migration rate, mortality rate, personal income tax rates, bond years to maturity, and indicators for whether the bond is callable, taxable, credit enhanced, and sold through competitive bidding. All regressions include state, year and month fixed effects. Standard errors, adjusted for clustering at the state-year level, are reported in parentheses. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1) Raw Yield	(2) Yield Spread	(3) Tax-Adjusted Yield Spread
(Predicted) Aging X Constitutional Protection	0.2075*	0.1893**	0.2051**
	(0.1256)	(0.0780)	(0.0859)
(Predicted) Aging	0.1950***	0.1876***	0.1900***
	(0.0754)	(0.0525)	(0.0545)
State and Bond Characteristics Controls	Yes	Yes	Yes
Fixed Effects	State, Year, Month	State, Year, Month	State, Year, Month
Observations	102,854	102,854	102,854
Adjusted R^2	0.58	0.26	0.44

the empirical specification in Table 8, we aggregate all variables at state level and run state-year panel regressions instead of bond-level regressions. We find that a one standard deviation increase in aged dependency ratio results in a 4.1 percentage point (about 19%) increase in pension liability ratio, and a 2.65 percentage point (about 28%) decrease in retiree healthcare funding ratio. These findings suggest that population aging makes it increasingly difficult for state and local governments to meet their obligations to public sector retirees, which could increase the cash flow risks of bondholders, and thus increase bond spreads.

4.3. Discussion: Pathways from aging to bond spreads

Having found evidence supporting each of the three hypotheses, we provide further regression-based evidence that helps verify a chain of causation that runs from aging to the subsequent pathways and then to bond spreads. Our approach involves regressing bond spreads on predicted aging, and then successively including as controls measures of the three intermediate pathways. If the inclusion of a control variable leads to declines in the coefficient on predicted aging, this would suggest that the variable represents an important pathway toward financing cost. This approach is similar to the pathway analysis approach used in Maccini and Yang (2009) and Andonov et al. (2018). Baron and Kenny (1986) first developed the methodology, and Imai et al. (2010) and Heckman and Pinto (2015) formalize it.

Table 11 presents the coefficient estimates of the IV regressions with and without controlling for measures of the three intermediate pathways. In Column (1), we recapitulate the point estimate and R^2 of the baseline IV regression for comparison with the subsequent regressions. The point estimate is 23 basis points and the R^2 is 0.26. In Columns (2) through (4), we additionally control for the natural logarithm of state personal income tax revenue per capita, pension liability ratio, and OPEB funding ratio, respectively.

All three variables are negatively correlated with bond spreads, consistent with our hypotheses. The coefficient on predicted aging has a positive sign across all three regressions, but the size of the coefficients and the R^2 of the regressions differ. The inclusion of tax revenue and pension funding ratio both lead to declines in the magnitudes of the coefficients on aging by 25–30%, and an

Table 10
Effect of Aging on State and Local Government Healthcare Spending and Pension Liabilities. This table presents IV estimates of the following system of equations: $Aging_{st} = \alpha_0 + \alpha_1 Birth\ Rates_{st} + \alpha_2' State\ Characteristics_{st} + \lambda_s + \lambda_t + v_{st}$, $Outcome_{st} = \beta_0 + \beta_1 \widehat{Aging}_{st} + \beta_2' State\ Characteristics_{st} + \eta_s + \eta_t + \epsilon_{st}$. The dependent variables are listed at the top of each column. Aging is the ratio of the population above 65 to the population between the ages of 15 and 64. Historical Rate is the sum of birth rates from 65 to 74 years ago. Aging and Historical Birth Rate are standardized to have a mean of 0 and a standard deviation of 1. Hospital Spending Per Capita is the per capita spending on the construction, acquisition, maintenance, and operation of hospital facilities, provision of hospital care, and support of public or private hospitals. General Health Spending Per Capita is the per capita spending on public health administration, research, and education, treatment and immunization clinics, environmental health activities such as air and water pollution control, and other general public health activities such as mosquito abatement. Pension Liability Ratio is the ratio of pension assets divided by state GDP. OPEB Funding Ratio is the ratio of OPEB asset to OPEB liabilities. Net Migration Rate is migration inflow minus migration outflow per 100 population. Personal and Corporate Income Tax Rate are the top marginal tax rates. State and year fixed effects are included in all regressions. Standard errors, adjusted for clustering at the state level, are reported in parentheses. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1) Log Hospital Spending Per Capita	(2) Log General Health Spending Per Capita	(3) Pension Liability Ratio	(4) OPEB Funding Ratio
(Predicted) Aging	0.2242*	0.0156	4.1039*	−2.6529
	(0.1273)	(0.1746)	(2.2236)	(6.5889)
<u>*State Characteristics*</u>				
Net Migration Rate (%)	0.1013	0.0926	−0.9344*	0.4941
	(0.0743)	(0.0565)	(0.4700)	(1.4228)
Log (Population)	0.2803	−0.2121	−3.8346	−19.4125
	(0.7237)	(0.5233)	(6.9348)	(29.6188)
Personal Income Tax Rate	0.0171	0.0117	0.5208*	0.1002
	(0.0477)	(0.0271)	(0.2965)	(0.2035)
Corporate Income Tax Rate	−0.0169	−0.0239	−0.2121	0.0282
	(0.0150)	(0.0181)	(0.1322)	(0.1034)
Fixed Effects	State, Year	State, Year	State, Year	State, Year
Observations	934	934	760	322
Adjusted R^2	0.92	0.82	0.05	−0.16

Table 11
How much do the mechanisms explain?. This table presents IV estimates of the following system of equations: $Aging_{it} = \alpha_0 + \alpha_1 Historical\ Birth\ Rates_{st} + \alpha_2 Intermediate\ Pathway_{st} + \alpha_3' State\ Characteristics_{st} + \alpha_4' Bond\ Characteristics_{it} + \lambda_s + \lambda_t + \lambda_m + \nu_{it}$, $Outcome_{it} = \beta_0 + \beta_1 \widehat{Aging}_{st} + \beta_1 Intermediate\ Pathway_{st} + \beta_3' State\ Characteristics_{st} + \beta_4' Bond\ Characteristics_{it} + \eta_s + \eta_t + \eta_m + \epsilon_{it}$. The dependent variables are listed at the top of each column. Aging is the ratio of the population above 65 to the population between the ages of 15 and 64. Aging is standardized to have a mean of 0 and a standard deviation of 1. Yield Spread is the difference between yields of a municipal bond and a coupon and maturity-equivalent synthetic Treasury bond Pension Funding Ratio is the ratio of pension asset to pension liabilities. Pension Liability Ratio is the ratio of pension assets divided by state GDP. OPEB Funding Ratio is the ratio of OPEB asset to OPEB liabilities. Control variables include the natural logarithm of population, net migration rate, mortality rate, personal top marginal income tax rates, and indicators for whether the bond is callable, taxable, credit enhanced, and sold through competitive bid. All regressions include state, year and month fixed effects. Standard errors, adjusted for clustering at the state-year level, are reported in parentheses. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1) Yield Spread	(2) Yield Spread	(3) Yield Spread	(4) Yield Spread	(5) Yield Spread
(Predicted) Aging	0.2270***	0.1627***	0.1693**	0.2060	0.1452
	(0.0527)	(0.0563)	(0.0808)	(1.0149)	(2.4550)
Log (Personal Income Tax Revenue Per Capita)		−0.1503*			−0.3230
		(0.0626)			(0.7990)
Pension Liability Ratio			0.3123***		0.3817
			(0.0876)		(1.2666)
OPEB Funding Ratio				−0.0006	−0.0006
				(0.0018)	(0.0038)
State and Bond Controls	Yes	Yes	Yes	Yes	Yes
Fixed Effects	State, Year, Month	State, Year, Month	State, Year, Month	State, Year, Month	State, Year, Month
Observations	102,584	102,584	87,046	42,796	42,796
Adjusted R^2	0.26	0.28	0.30	0.32	0.36

increase in the adjusted R^2 from 26% to 28% and 30%, respectively. By contrast, although the inclusion of OPEB funding ratio improves the adjusted R^2, its inclusion only decreases the coefficient on aging by about 9%. In Column (5), we include all three hypothesized intermediate pathways as control variables in the IV regression. The resulting coefficient on population aging decreases from over 24 basis points to about 14 basis points, representing an over 36% drop. The standard errors increase in the last three specifications because of the sample size reduction caused by pension and OPEB data limitations. Overall, these results provide suggestive evidence that reduced tax revenue and increased pension liabilities are the most important mechanisms through which aging affects bond spreads, whereas underfunded OPEB liabilities play a relatively smaller role.

Although this pathway approach is intuitive, it is worth considering the underlying econometric assumptions and their plausibility. Imai et al. (2010) note that the key assumption behind this channel analysis approach is "sequential ignorability." First, given the observed covariates, the treatment assignment—in our case, population aging—is statistically independent of potential outcomes and potential channels; second, the channel is statistically independent of potential outcomes given the observed treatment and covariates. The first part of the sequential ignorability assumption is plausibly satisfied in our case because, by using an instrumental variable, we only rely on the variation in population aging stemming from historical birth rates, which should be independent of current government financial conditions. However, the second part of the sequential ignorability assumption is very strong in our setting because it requires tax revenue and retiree liabilities to be as good as "randomly assigned" with respect to bond spreads, conditional on population aging rate, control variables, and fixed effects. Given the strong econometric assumption and the data limitations on pension and OPEB liabilities, our estimation of the explanatory powers of the mechanisms should only be taken as suggestive, rather than causal.

5. Conclusion

The population age structure of the United States experienced a systematic change in the past decade and is projected to shift at a similar pace in the next 30 years. This demographic shift comes at a time of already deteriorating government fiscal health. Following the recent financial crisis, the combination of precipitous home value drops, inefficient infrastructure investments, and escalating personnel costs has led to the defaults of Jefferson County, Stockton, Detroit, and many other municipalities (Moody's (2017)). The recent COVID-19 pandemic and its associated lockdown measures may lead to further reductions in local tax revenues and fees, and an increase in municipal spending to fight the pandemic.[12]

The precise impact of population aging is difficult to measure, as aging is closely tied to various aspects of state macroeconomic conditions that are ultimately determinants of governments' income and expenses. In this paper, we quantify the effect of population age structure change on state governments through the lens of their municipal bond market outcomes. We find that a one standard deviation increase in state population aging, measured by the ratio of the population above 65 to the population between the ages of 15 and 64, leads to a 22–24 basis point increase in state and local government General Obligation bond issue yield spread. Three channels contribute to this effect. First, aging decreases state tax revenues, especially personal income tax revenues. Second, aging increases state unfunded pension obligations. Third, aging increases state retiree healthcare liabilities.

Our findings suggest that demographic changes not only can directly impact state governments' balance sheets, but also can indirectly impact state governments' fiscal conditions through affecting their cost of accessing the financial market. Our results also highlight the challenges U.S. state and municipalities face to cope with the systemic demographic transition.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpubeco.2022.104665.

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[12] See, for example, https://www.washingtonpost.com/local/local-governments-in-dc-region-revise-budgets-halt-projects-to-blunt-economic-impact-of-covid-19/2020/04/08/3d456b8e-79a0-11ea-a130-df573469f094_story.html.

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