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Who supports carbon pricing? Older adults' financial literacy and attitudes toward carbon taxation



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ABSTRACT

We investigate how financial literacy impacts older adults' views on carbon taxation and climate fiscal policies. Using a representative survey in Singapore, we find that financially savvy older adults are generally less supportive of climate fiscal policies in that they are less likely to perceive carbon tax as fair or believe that increasing carbon tax will help increase employment. We provide empirical evidence that these relationships are causal. Interestingly also, the negative causal effect of financial knowledge on older adults' attitudes towards carbon taxes is predominantly driven by their inflation literacy. Those more knowledgeable about inflation have higher awareness that carbon pricing can lead to higher costs of production and costs of living. Other personal factors that shape older adult's attitudes on carbon taxation include age, marital status, and income. As future cohorts of elderly become more financially literate, communication campaigns on climate change and carbon taxation directed towards older demographic groups are urgently warranted.

Introduction

Climate finance and carbon pricing are regarded as sustainable policy mechanisms for mitigating negative environmental externalities. Indeed, many countries are advancing in the implementation of carbon pricing and broader energy transition efforts (World Bank, 2024; Ba & Tan, 2025). Despite the growing societal awareness of climate change, however, public support for carbon pricing is often divided. On the one hand, many economists proclaim carbon tax to be one of the most effective ways to discourage carbon consumption and lower the risks of catastrophic climate change since it is a relatively simple instrument to impose on individual emitters without being technologically prescriptive (Mankiw, 2009; Baranzini et al., 2017; D'Andrea Tyson, 2013; World Bank, 2024). On the other hand, it appears that many people are still unconvinced. A global survey among climate policy researchers across a wide range of disciplines shows that whilst some disciplines like engineering and psychology share the opinion of economists, other discipline clusters hold less favorable views about carbon pricing (Drews et al., 2024). For instance, mathematicians and computer scientists tend to evaluate carbon pricing less positively than economists (Savin et al., 2024). The lack of public support for carbon taxes has policy consequences. In 2018, for example, the Yellow Vest uprising in France was triggered by rising fuel prices and an unpopular fuel tax (Carattini et al.,

2019). The proposed eco-tax was subsequently scrapped by the French government. Carbon taxation also continues to be politically elusive in the United States, which lacks a national-level carbon pricing policy. Notably, initiatives to implement carbon pricing in the state of Washington were rejected twice by voters in 2016 and 2018 (Karczeski, 2022).

Past studies have highlighted that pro-environmental attitudes and support for climate fiscal policies tend to be weaker among older individuals than younger individuals (Andor et al., 2018; Carattini et al., 2019; Fairbrother et al., 2019; Sivonen & Koivula, 2024). For instance, Fairbrother et al. (2019) show empirically that younger generations are more supportive of fossil fuel taxes than older generations across 23 European countries. Andor et al. (2018) find that older German adults are generally more skeptical about the existence and anthropogenic character of climate change and thus less likely to support climate-friendly policies such as the subsidization of renewables. Aside from climate skepticism, another reason may be traced to the disproportionate burden of additional expenditure and greater income inequality under new carbon pricing regimes borne by older adults as compared to younger persons in the same income group (Tian et al., 2023). While it is widely recognized that older adults are less supportive of climate fiscal policies in general, less is known about what factors determine older adults' climate-related policy preferences and, in particular, whether financial illiteracy plays a critical role in this relationship.

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Older adults constitute a vulnerable population subgroup with lower-than-average levels of financial literacy in many countries. Notably, empirical studies in the US and several European countries have evidenced that financial literacy is lowest among the young and the old (Alessie et al., 2011; Bucher-Koenen & Lusardi, 2011; Lusardi & Mitchell, 2014). Furthermore, theoretical work based on multiperiod dynamic life cycle models whereby individuals both select capital market investments and invest in the acquisition of financial knowledge suggests that endogenously determined optimal paths for financial knowledge are hump-shaped over the life cycle (Lusardi & Mitchell, 2014). The fact that many older individuals have a limited grasp of basic finance concepts is a concern since financial knowledge is linked to a number of economic behaviors such as savings and retirement planning (Lusardi & Mitchell, 2011, 2014); stock market participation (Van Rooij et al., 2011); and timely credit card debt repayment (Fong et al., 2021). This concern is potentially more acute in a country like Singapore given its long-established national defined contribution social security system where residents have to assume primary responsibility for providing for their own retirement needs (Fong, 2025). Also, many older Singaporeans received little to no formal financial education in their youth, as the national financial literacy initiative, MoneySense, was only launched in 2003. Koh et al. (2020) report that close to half of Singaporeans aged 50–70 anticipate that they will struggle in retirement, even though their levels of financial literacy are comparable overall to that of older adults in the United States.

This paper explores the determinants of older adults' policy preferences towards climate fiscal policies and carbon taxation, focusing on the impact of financial literacy (or illiteracy) on such attitudes. We use a representative survey of older adults in Singapore, a city state in Southeast Asia, which has implemented a carbon pricing scheme since 2019. The 2023 online survey elicits different measures of people's climate-related policy preferences including their beliefs on whether a carbon tax is fair, whether a tax increase may affect employment opportunities, and their attitudes towards pension investments in eco-friendly businesses. We assess financial knowledge level using the standard "Big Three" financial literacy questions devised by Lusardi and Mitchell (2008, 2011) and implement instrumental variable (IV) regressions to investigate causal linkages between older adults' financial knowledge and their attitudes toward climate fiscal policies.

Singapore is an appealing setting for our investigation as it is the first country in Southeast Asia to introduce a carbon emission tax. Singapore has been a developed nation for many years. As a city-state, Singapore is characterized by a dense built-up urban environment with no hinterland and limited natural resources. Thus, improving energy efficiency is a key policy strategy for reducing emissions in all sectors of the economy, given the nation's limited potential for alternative energy sources. Also notably, Singapore has consistently ranked among the highest emitters for greenhouse gases on a per capita basis. Fig. 1 shows that Singapore ranked 24th globally in per capita greenhouse gas emissions and 21st in per capita carbon dioxide emissions in 2022 (World Bank, 2024). While Singapore's emissions per capita is lower than that of some other developed countries such as the United States, Brunei, and Australia, it is still about twice that of the world average. In September 2016, Singapore ratified the Paris Agreement and pledged to reduce its emissions intensity by 36 % from 2005 levels by 2030. Singapore's carbon tax, implemented on 1 January 2019, was initially set at S\$5/tCO₂e and uniform across all sectors.¹ Accordingly, it is of interest to understand how Singaporeans perceive carbon taxation and climate fiscal policies, including whether they think such a tax is fair.

According to official sources, the carbon tax revenues are consolidated by the Singapore government and allocated to different projects and schemes that support decarbonization efforts, help businesses be more energy-efficient, and cushion the impact of higher costs on

households (National Environment Agency, 2025). This includes increased funding for existing schemes such as the *Energy Efficiency Grant* and the *Resource Efficiency Grant for Emissions*, which support improvements in energy efficiency in the industrial sector (Economic Development Board, 2025). For example, the *Energy Efficiency Grant* supports businesses—mostly in the food services, food manufacturing and retail sectors—in their sustainability journey by co-funding investments in energy-efficient equipment. The *Resource Efficiency Grant for Emissions* provides monetary support for industrial facilities to undertake energy efficiency projects. Under the Climate Friendly Households Programme, launched in 2020, eligible households were given vouchers to offset the purchase of various energy- and water-efficient appliances and fittings. These schemes are also widely covered in the local media (Tan, 2022; ChannelNewsAsia, 2024), leading to much public attention towards carbon taxation issues.

Our study contributes to the extant literature by offering a comprehensive examination of the impact of financial knowledge on attitudes towards climate fiscal policies at the individual level. We consider not only people's perception of whether a carbon tax is fair, but also their views regarding how carbon taxation may potentially affect their employment and pension investments. With climate change and carbon taxation policies increasingly affecting individuals' day-to-day lives, how people perceive such policies can influence their subsequent mitigation and adaptation behaviors. In that way, our study adds to a small but growing body of work that has examined links between financial literacy and personal climate change coping behaviors (Boogen et al., 2021; Filippini et al., 2020; Köppel & Schratzenstaller, 2023). Furthermore, our investigation of the causal relationship between financial knowledge and attitudes towards climate fiscal policies—using instrumental variable methods—helps address potential endogeneity concerns. This is critical as financial knowledge may be endogenously determined with respect to the economic behavior and perceptions of individuals (Lusardi & Mitchell, 2014). This approach enhances both the precision of model estimations and the reliability of derived outcomes and policy implications. To the best of our knowledge, our paper is the first to analyze whether financial literacy is a causal determinant of attitudes toward climate fiscal policies among older adults.

The remainder of this paper is organized as follows. We first present the literature review, conceptual framework, and hypotheses. This is followed by a description of the survey data and methodology. Next, we report our empirical findings, including results from the instrumental variable regression. Robustness checks are also reported. The final section concludes.

Literature review and background

In this section, we begin with a review of past research on climate-related policy preferences among individuals and households. The key determinants of such preferences are also detailed. Second, we introduce the literature relating to financial knowledge and its measures. We also highlight the importance of accounting for the potential endogeneity of financial literacy in empirical analyses. Third, we showcase a small but growing body of research that has evidenced links between financial knowledge and personal climate change adaptation behaviors, and outline our main hypotheses.

Determinants of climate-related policy preferences

A significant body of research on environmental and climate-related policy preferences has documented fairly clear divides in the views of people across different demographic groups (Drews & Van Den Bergh, 2016; Ergas & York, 2012; Harring et al., 2017; McCright, 2010; Steg et al., 2014; Montagnoli et al., 2017). For example, studies suggest that women are, in general, more likely than men to support environmental protection, attributable in part to their traditional roles as caregivers, subsistence food producers, and reproducers of human life (Ergas &

¹ tCO₂e refers to tonnes of carbon dioxide equivalent.

Panel A. Carbon dioxide emissions per capita in 2022 (tCO₂e)

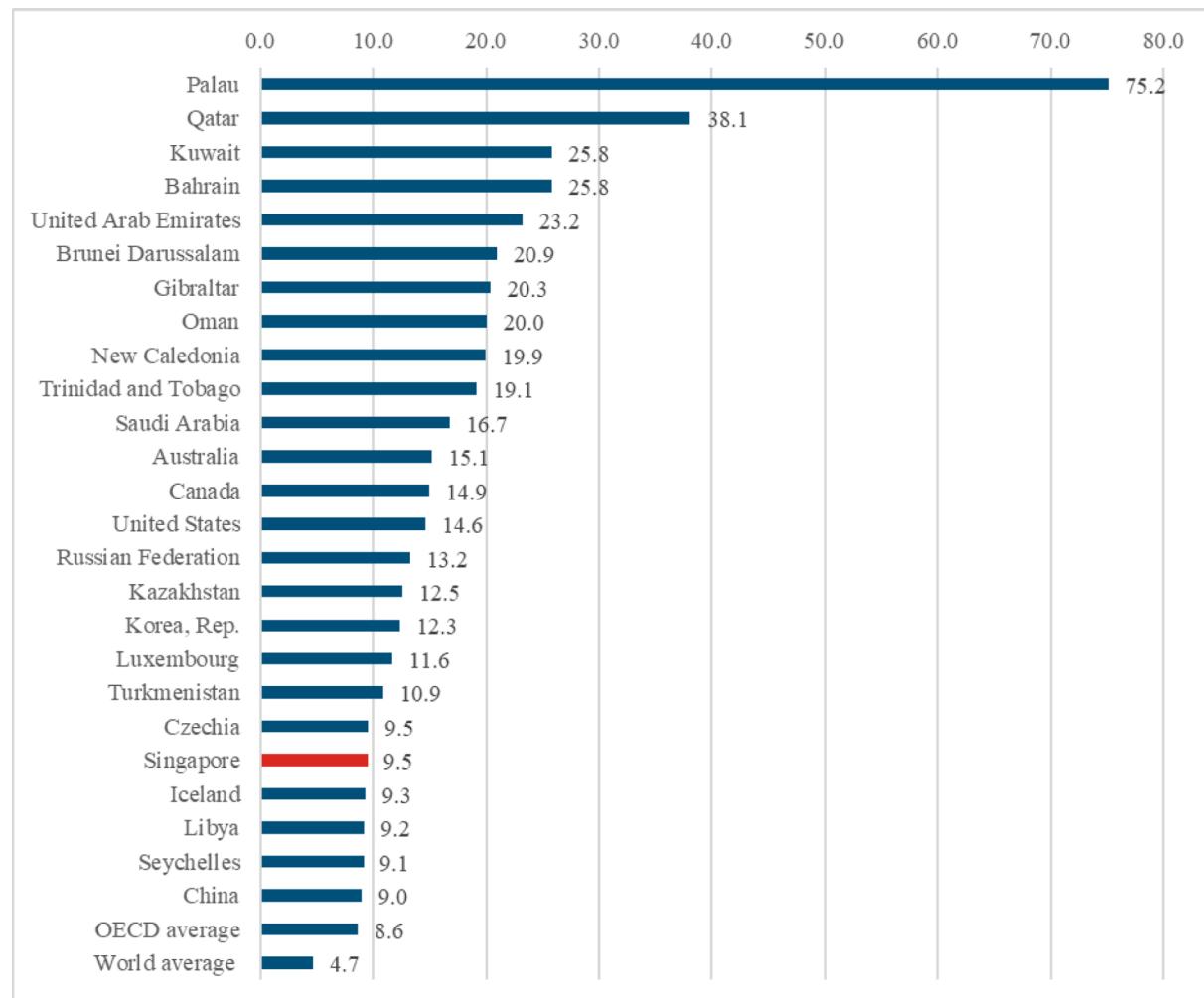


Fig. 1. Carbon dioxide and greenhouse gas emissions of Singapore in the world Panel A. Carbon dioxide emissions per capita in 2022 (tCO₂e) .

Source: Authors' own, based on data extracted from World Bank Group (2024). Note: Singapore ranked 21st globally for carbon dioxide emissions per capita in 2022. tCO₂e = tons (t) of carbon dioxide (CO₂) equivalent (e). Panel B. Total greenhouse gas emissions per capita in 2022 (tCO₂e) Source: Authors' own, based on data extracted from World Bank Group (2024). Note: Singapore ranked 24th globally for the total greenhouse gas emissions per capita in 2022. tCO₂e = tons (t) of carbon dioxide (CO₂) equivalent (e)

York, 2012; McCright, 2010). Using data from more than 20 European countries, Fairbrother et al. (2019) demonstrate empirically that women are more supportive of fossil fuel taxes than men. Research also shows that socio-economic status is another key determinant of public views towards climate fiscal policies. Higher income earners and more educated individuals tend to be more supportive of climate fiscal policies and carbon taxes (Fairbrother et al., 2019; Kallbekken et al., 2013). Since carbon tax represents a direct personal cost to consumers, lower-income families who spend a larger share of their income on carbon-intensive goods may be harder hit (Fremstad & Paul, 2019).

Age is another key determinant of climate-related policy preferences. Younger adults are generally more supportive of climate change mitigating policies than older adults. For example, Sivonen and Koivula (2024) show that age is negatively associated with support for fossil fuel taxes in Finland, Norway, and Sweden. One study finds that older

Germans exhibited weaker support for renewable energy resources, were less likely to believe in the importance of climate change policy, and had lower willingness to pay for an additional carbon tax (Andor et al., 2018). The authors attribute these findings to older adults' skepticism toward climate change. Tian et al. (2023) highlight that another possible reason for older adults' weaker support of carbon taxation may be the disproportionate burden of additional expenditure that they are likely to bear under new carbon pricing regimes. Using empirical simulations and multi-country data, that study estimates that the relative gap between the impact of carbon pricing on elderly and younger groups can exceed 20 % in less wealthy countries, such as those in Eastern Europe.

Political ideologies, trust, and personal beliefs also influence public acceptability for climate fiscal policies. One study finds that free-market ideology is negatively associated with support for carbon pricing in

Panel B. Total greenhouse gas emissions per capita in 2022 (tCO2e)

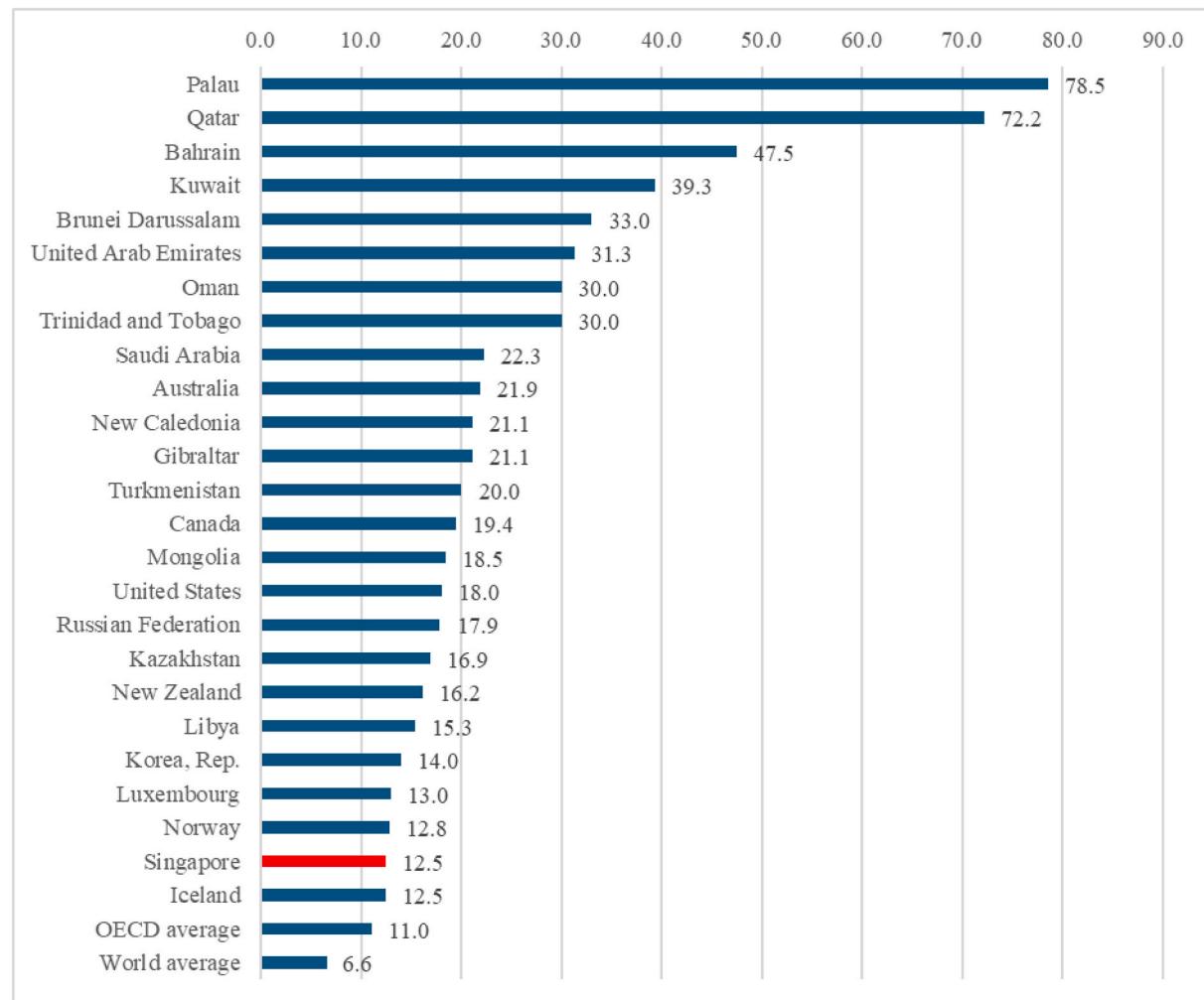


Fig. 1. (continued).

Australia (Dreyer & Walker, 2013). Some studies report that left-wing political ideology is related to stronger support for carbon taxes in Brazil, Germany, Sweden, and the United States (Jagers et al., 2024; Larsson et al., 2020). Political trust and personal feelings of moral duty in addressing climate change are both evidenced to be positively associated with support for climate fiscal policies (Fairbrother et al., 2019; Larsson et al., 2020; Sivonen & Kukkonen, 2021; Zhang et al., 2021). In contrast, negative perceptions and lack of trust in the government tend to reduce public support for carbon taxes (Davidovic, 2024). Using survey data from Spain before and after the first wave of COVID-19 and allowing for both aggregate and within-person analyses, Drews et al. (2022) find that higher climate policy acceptance is associated with a positive opinion about how the government addressed the COVID-19 crisis. That study also showed that trust in politicians, values of climate concern, as well as political orientation, are predictive of post-COVID-19 carbon tax acceptance among households. Also in the context of Spain, Maestre-Andrés et al. (2021) find that revenue uses, prior knowledge, and information provision about the functioning of carbon taxation can affect policy perceptions and acceptability of carbon taxation.

Literature on financial knowledge

Financial knowledge is defined as "having a basic knowledge of

financial concepts and the ability to apply numeracy skills in financial contexts" (OECD, 2023). Economists measure financial knowledge (or financial literacy) by testing individuals' ability to correctly answer quiz-like questions on fundamental financial and economic concepts relating to time value of money, inflation, interest rates, risk diversification, and others.² One of the most popular financial literacy measures—survey questions that have been dubbed the Big Three—was developed by Lusardi and Mitchell (Lusardi & Mitchell, 2008, 2011). The Big Three questions test individuals' understanding of interest rates, the workings of inflation, and risk diversification. Given its simplicity, relevance, brevity, and ability to differentiate respondents' knowledge (Lusardi & Mitchell, 2014), the Big Three question set has been used in household surveys around the world. This also includes many retirement, aging and health surveys targeting older adults. For instance, Kim et al. (2021) report an average financial literacy score of 2.00 among Americans aged 50+ in the 2016 Health and Retirement Survey. Alessie et al. (2011) report an average score of 2.14 among Dutch individuals

² In the economics and household finance literature, the terms "financial knowledge" and "financial literacy" are often used interchangeably (Lusardi & Mitchell, 2011, 2014). A broader term that is related to this field is "financial capability," which includes financial knowledge, financial behavior, and financial self-efficacy.

aged 51 and older, while Yu et al. (2023) find an average score of 0.76 among respondents aged 50 + in the 2015 China Household Finance Survey.

Closer to our context, Koh et al. (2020) and Fong et al. (2021) report that Big Three financial literacy score averages about 2.01–2.02 among more than 6000 Singaporeans aged 50–70 in the online Singapore Life Panel survey. Also using an online survey, Sconti and Fernandez (2023) find that 78 %, 75 %, and 50 % can correctly answer the interest rate, inflation and risk questions, respectively, among Singaporeans aged 23–86.³ Notably, the Singapore government conducted the inaugural MoneySense National Financial Capability Survey in 2021 and used non-probability quota sampling to form a nationally representative sample. Furthermore, face-to-face interviews were conducted to ensure high quality data. In the national survey covering Singaporeans aged 19 and above, 88 %, 71 % and 57 % correctly answered the interest rate, inflation, and risk question, respectively (Fong, 2025).

Accordingly, we implement the Big Three questions to assess the financial literacy of our respondents aged 55 and above in the present study. Respondents are individually scored on the number of correct answers (shown in bold face below) that they furnish to these three questions phrased as follows:

(i) Suppose you had \$100 in a savings account and the interest rate was 2 % per year. After 5 years, how much do you think you would have in the account if you left the money to grow? [more than \$102; exactly \$102; less than \$102; don't know].

(ii) Imagine that the interest rate on your savings account was 1 % per year and inflation was 2 % per year. After 1 year, with the money in this account, would you be able to buy... [more than; exactly the same as; less than today; don't know].

(iii) Is this statement true or false? "Buying a single company stock usually provides a safer return than a Unit Trust (or stock mutual fund)." [true; false; don't know].

Many studies have evidenced the positive impact of financial literacy on financial decision-making among individuals and households. These studies show that financially knowledgeable people are more likely to save and accumulate wealth (Behrman et al., 2012; Lusardi & Mitchell, 2014); plan for retirement (Alessie et al., 2011; Bucher-Koenen & Lusardi, 2011; Lusardi & Mitchell, 2008, 2011; Niu et al., 2020); have emergency funds (Zhang & Chatterjee, 2023); participate in stock markets (Van Rooij et al., 2011); hold fixed deposits as a form of saving; repay bills on time (Fong et al., 2021); and avoid high-cost consumer borrowing (Disney & Gathergood, 2013). In Singapore, Koh et al. (2020) show that Big Three financial literacy is positively associated with respondents having both more wealth, as well as more diversified and complex portfolios. Fong (2025) shows that financially literate Singaporeans have more debt, but they are also far more likely to repay their debt on time. Interestingly, Sconti and Fernandez (2023) find that a positive correlation between financial literacy and Environmental, Social, and Governance (ESG) literacy in Singapore, i.e., those with higher ESG knowledge tend to be more financially literate. Using data from Singapore's national financial literacy survey, Fong and Mitchell (2025) document that about 31.4 % of Singaporean households hold individual stocks; in addition, respondents' Big Three financial literacy has positive causal effects on stockholding both inside and outside of pension plans.

Also important in this literature is the argument that financial literacy itself may be endogenous. This is because financial knowledge is a

form of investment in human capital; individuals choose whether to invest in financial literacy by evaluating the costs and benefits of doing so over their life cycle (Kim et al., 2021; Lusardi & Mitchell, 2014). Thus, people's financial literacy can be endogenously related to their wealth and wealth inequality, so care is needed to identify and quantify the causal relationship between financial knowledge and related financial behaviors. The standard approach for dealing with these endogeneity problems in the mainstream literature is to analyze the impact of financial literacy with instrumental variables (IV) methods. Empirical studies using IV estimations have shown that financial literacy has a direct causal effect on wealth accumulation (Behrman et al., 2010), retirement planning (Lusardi and Mitchell, 2011), stock market participation (Van Rooij et al., 2011), and financial asset ownership (Fong, 2025). In all of these cases, the IV financial literacy estimates prove to be larger than the ordinary least squares (OLS) estimates, which implies that the noninstrumented estimates of financial literacy may underestimate the true effect (Lusardi and Mitchell, 2014). In relation, a number of studies such as Alessie et al. (2011), Van Rooij et al. (2011), Agnew et al. (2012), Bannier and Schwarz (2018), Grohmann (2018), and Fong (2025), highlights the relevance and efficacy of using the financial experiences of one's siblings and/or parents as an instrumental variable in IV regressions to establish causality between financial knowledge and financial behavioral outcomes. For example, Van Rooij et al. (2011) instrumented on the financial situation of the oldest sibling when examining the relationship between financial knowledge and stock market participation.⁴ We thus adopt similar methodological approaches in our current study.

Financial knowledge and public attitudes towards carbon taxation

Despite the rich literature on financial literacy, there is scant research on the relationship between financial knowledge and public attitudes towards climate fiscal policies. There are at least two reasons why it is valuable to investigate this relationship.

First, carbon taxes drive up energy prices and have economic consequences. Designed to internalize social and environmental costs of economic activities into market prices, carbon tax and other forms of environmental taxes may directly impact consumer prices or indirectly do so via affecting production costs. On the supply side, the increase in production costs may drive up inflation, resulting in lower production. For example, one study shows that carbon pricing initiatives in Europe have led to a persistent fall in output, increase in consumer prices, and a rise in unemployment rate (Käenzig, 2023). Given the strong links between financial knowledge and economic decision-making as established in prior studies, it is reasonable to believe that financial knowledge may also play a role in influencing people's views on whether and how carbon taxation may affect the overall economy and employment rate, and more broadly, their perceptions of whether such a tax is fair.⁵ Moreover, several recent studies have begun to investigate

⁴ The exact wording of the question used in constructing the instrumental variable is: "Would you say that your oldest [brother/sister] is in worse, better, or about the same financial condition than you?" Grohmann (2018) and Fong (2025) both utilized the respondents' rating of parental understanding of financial matters as an instrumental variable in establishing the causal impact of financial literacy on household saving and borrowing decisions.

⁵ Arguably, fairness is a broad concept. In the context of carbon taxation, Dreyer and Walker (2013) define fairness in terms of distributive justice (outcomes received from the policy and how those compare to the outcomes others receive), as well as procedural justice (to the processes that were used to inform the outcomes). That study also showed that people's perceived fairness on carbon emission reduction translates into greater general support for carbon taxation. In relation, Kallbekken et al. (2013) and Larsson et al. (2020) documented people's expectations of how carbon taxes may influence their personal finance and personal freedom contribute to their views on whether such policies are fair.

³ Also, Sconti and Fernandez (2023) state that the average age of their sample (46 years; N=1699) is higher than that of the population in Singapore (42 years). Hence, sampling weights were applied in that study to ensure findings are representative of the Singaporean population. In contrast, our study focuses exclusively on the older demographic (rather than the general population). As our analytical sample closely mirrors the older resident population in terms of sex, race/ ethnicity, and age composition (see next section for details), sampling weights are not applied in the current study.

the link between financial literacy and public decisions such as citizens' engagement in politics and decision-making, voting behavior, as well as attitudes toward economic and pension reforms (Fornero & Lo Prete, 2019, 2023; Oggero et al., 2023).

Second, a small but growing body of work has found links between financial knowledge and personal climate change coping behaviors. Filippini et al. (2020) showed that Big Three financial literacy, alongside people's general knowledge of energy use and costs, is positively associated with their willingness to replace energy-inefficient appliances in Nepal. Boogen et al. (2021) analyzed the level of efficiency in the use of electricity in the European residential sector and found that the cognitive abilities of the households in doing an investment calculation play a more important role than the energy-related knowledge in explaining the outcome. Respondents with stronger cognitive abilities (measured in part by the Big Three questions) had a lower level of inefficiency in electricity consumption. However, a key limitation is that none of these studies acknowledged the possible endogeneity of financial literacy or performed instrumental variable estimations.

Our study extends these strands of literature while contributing primarily to the financial literacy literature by investigating whether, and how, basic financial knowledge affects public support toward climate fiscal policies. Given the growing evidence that financial literacy affects personal climate change mitigation and adaptation behaviors and the fact that climate change increasingly affects individuals' day-to-day lives, it is reasonable to hypothesize that Big Three financial knowledge may also influence individuals' preferences about climate fiscal policies. We seek to fill this important research gap. Moreover, following the mainstream literature on financial literacy, we explicitly take into account the potential endogeneity of financial knowledge in our empirical analyses. Doing so allows us to identify and quantify the causal relationship (if any) between Big Three financial knowledge and the various climate-related attitudinal outcomes, thus augmenting the international literature on the economic importance of financial literacy.

Data overview and summary statistics

Collection of primary data by survey

We use primary data collected through an online survey conducted in Singapore. Ethical approval for the survey was obtained from the Institutional Review Board of the National University of Singapore (NUS-IRB-2023-957) and all participants provided written informed consent. The purpose of the survey was to assess the attitudes and perceptions of carbon taxation policies and emissions-related costs among adults aged 55 and above in the city-state, considering that Singapore is the first country in Southeast Asia to introduce a carbon emission tax. Age 55 was chosen as the threshold because it is the age at which pension benefits become accessible to most Singaporeans in the nation's defined contribution retirement system. The online survey was conducted in English (the official language of Singapore) and rolled out in December 2023. The anonymized dataset contains information on sociodemographics, financial knowledge, perceptions of climate change, attitudes towards carbon taxation, energy use behaviors, and other related aspects. The sample comprises 1,000 Singaporean residents aged 55 and above, and the data are largely complete.

Sample descriptive statistics

Table 1 displays the characteristics of the sampled respondents. The average age is 64.4 years. The male-to-female ratio in our sample is 50:50, which closely resembles the 48:52 sex ratio reported in the 2023 Singapore resident population profile for the adult population within the age bounds of our analytical sample (Department of Statistics of Singapore, 2024). 75.4 % are married and 26.3 % have a university degree or above. About three in five respondents (or 59.9 %) are currently employed in the formal workforce, while the remaining 40.1 %

Table 1
Sample description.

Variable	Mean	SD
Financial literacy	2.16	0.95
Age (years)	64.41	7.09
Have a university degree or above	0.26	0.44
Male	0.50	0.50
Married	0.75	0.43
Larger household size	0.72	0.45
Employed	0.60	0.49
Household monthly income		
Less than \$5,000	0.25	0.43
\$5,000 and <\$10,000	0.27	0.44
\$10,000 and <\$15,000	0.31	0.46
≥\$15,000	0.16	0.37
Prefer not to say	0.02	0.12
Race/ ethnicity		
Chinese	0.76	0.43
Malay, Indian, and others	0.24	0.43
High risk tolerance		
Yes	0.21	0.41
No	0.79	0.41
Sibling's financial situation		
No sibling or don't know	0.13	0.34
Worse	0.09	0.29
The same or better	0.78	0.42
Policy awareness		
Know	0.56	0.50
Do not know	0.44	0.50
Climate concern		
Most scientists think climate change is happening	0.73	0.44
Most scientists think climate change is not happening	0.09	0.29
There is a lot of disagreement among scientists	0.08	0.27
Do not know	0.10	0.29

Notes: SD = standard deviation. N = 1,000. Sample is representative of the older demographic; no weights are applied.

are retired or unemployed. The portion of individuals with a larger household size (three persons or above) is 71.8 %. In terms of household monthly income, 24.8 % of the respondents report earning less than \$5,000, 26.9 % earn between \$5,000–9,999, 30.7 % earn between \$10,000–14,999, 16.1 % have a monthly income of \$15,000 or more, and a small handful of respondents preferred not to say.⁶ See Appendix Table A1 for detailed variable definitions.

Overall, our analytical sample closely mirrors the older resident population in terms of sex, race/ ethnicity, and age composition. 76.2 % of the respondents are Chinese, and 23.8 % of them are Malay, Indian or other ethnic groups, which is similar to the census averages for the older subpopulation at the time of the survey.⁷ The average Big Three financial literacy score in our sample is 2.16, which is similar albeit slightly higher than the average score of 2.01–2.02 reported by Koh et al. (2020) and Fong et al. (2021) for Singaporeans aged 50–70. A key difference is that our survey was conducted more recently in 2023 whereas those earlier studies utilized microdata collated between 2015 and 2017. Accordingly, we use the Big Three score as our measure of financial literacy in main empirical analysis.

The Big Three score is fundamentally based on three separate quiz questions testing individuals' understanding of interest rate, inflation, and risk diversification in capital markets. Respondents were provided

⁶ All amounts are expressed in Singapore dollars. The average Singapore Dollar (S\$) to US Dollar (US\$) exchange rate in 2023 was 1 S\$ = 0.7447 US\$. Those respondents with missing income values (i.e., who prefer not to say) comprise only 1.5% of the sample and are included in the analyses as a category with other income groups. There is complete data for all other covariates.

⁷ 79.7% are Chinese and 20.3% are Malay, Indian or other ethnic groups, in the national resident subpopulation. Further comparisons for age and sex are provided in Appendix Table A2. The census averages are based on the 2023 Singapore resident population profile and restricted to ages 55–89, thus consistent with the age bounds for our analytical sample.

with a “Don’t know” option in each case and were not allowed to skip these questions in the online survey. Appendix Table A3 summarizes the responses to the three questions. Panel A provides a breakdown by question, as well as summary statistics on cross-question consistency. We note that 88.0 %, 70.7 % and 57.3 % correctly answered the interest rate, inflation, and risk diversification question, respectively. The proportion who answered “don’t know” to all three questions is low at 3.4 %. 47.2 % of respondents answered all three questions correctly. These patterns of responses among older Singaporean adults are consistent with those documented in Fong (2025) for a broad cross-section of the Singaporean resident population,⁸ and can be partly attributable to the fact that basic financial concepts such as budgeting, compound interest, and delayed gratification are woven into the school curricula whereas more advanced concepts like risk diversification are not (Ministry of Education, 2020). Given that the proportion of correct answers varies by question, we thus consider an alternative specification of financial literacy in robustness check by using three separate indicator variables (=1 if a respondent answered that particular quiz question correctly, 0 else) in lieu of the respondent’s cumulative Big Three score. Additionally, Panel B shows financial literacy level across key sociodemographic subgroups. The proportion of respondents who answered all three questions correctly is higher among males than females, and higher among those with university education and those currently employed in the workforce.

Findings regarding attitudes towards climate fiscal policies

Our outcome variables focus on people’s attitudes toward carbon tax policy. Specifically, the three outcomes examined are: (i) *think carbon tax is fair*, (ii) *believe higher carbon tax increases employment*, and (iii) *support pension investments in green businesses*. The exact question for the first variable was phrased as follows: “To what extent do you think carbon tax is fair?” Answers were recorded on a five-point scale: 1 = “Not fair at all”, 2 = “Somewhat unfair”, 3 = “Somewhat fair”, 4 = “Fair”, 5 = “Very fair”. For the second variable, respondents were asked: “How do you think an increase in the carbon tax will affect Singapore’s economy, in terms of employment?” Answers were recorded on a five-point scale: 1 = “Significant decrease in jobs”, 2 = “Slight decrease in jobs”, 3 = “Negligible changes in jobs”, 4 = “Slight increase in jobs”, 5 = “Significant increase in jobs”. In both cases, a higher score indicates greater support for carbon taxation. Previous studies have assessed support for carbon taxes using similar questions (e.g., Savin et al., 2020).⁹

The third outcome focuses on people’s attitudes toward investing pension funds in eco-friendly businesses. Given the global transition to a low-carbon and climate resilient economy, pension funds and other institutional investors potentially have an important role to play in financing these green growth initiatives. The attitudes and preferences of pension plan participants and beneficiaries may, to some extent, influence whether a pension fund ultimately decides to invest in green businesses, as well as adopt environmental, social, and governance investing to screen investments based on corporate policies so as to encourage companies to act responsibly. Furthermore, Singapore’s national defined contribution pension system—known as the Central Provident Fund (CPF)—allows plan participants to invest a portion of their pension accumulations in stocks, mutual funds, and other financial

⁸ Using the 2021 MoneySense National Financial Capability Survey and a sample comprising 2451 adults aged 19 and above, Fong (2025) reports that 88.0%, 70.7% and 57.3% correctly answered the interest rate, inflation, and risk diversification question, respectively; also, 49.2% of respondents answered all three questions correctly.

⁹ For instance, in Savin et al. (2020), one of the questions asks: “How fair or unfair do you consider a carbon tax?” (Response options: very unfair, somewhat unfair, neither unfair nor fair, somewhat fair, very fair).

instruments via a self-directed investment scheme; there is no age limit for participating in the CPF investment scheme.¹⁰ In our survey, respondents were asked: “Would you be supportive if the pension fund in Singapore invests in businesses that are committed to addressing climate change?”. Dichotomous responses were recorded (0 = “No”, 1 = “Yes”).

Fig. 2 illustrates the distribution of responses for each of the outcome variables. The responses for the first and second outcome variables are about normally distributed. The mean score for *think carbon tax is fair* is 3.29 (SD = 0.97), while the mean score for *believe higher carbon tax increases employment* is 2.72 (SD = 0.89). In each case, we excluded the small handful of respondents with missing values for that variable.¹¹ In terms of *support pension investments in green businesses*, 43.9 % of sampled respondents said “yes”, 36.1 % said “no”, and 20 % said “do not know”. The relatively higher proportion of missing values for the third outcome variable may be attributable to the fact that most Singaporeans do not take an active role in deciding their pension fund allocation in the CPF. For instance, Fong (2020) documents that only about one in four CPF plan participants used the self-directed investment options available in the pension system over 2004–2018. Most Singaporeans prefer to leave their pension balances in the default government-run CPF fund which offers risk-free interest returns. Thus, the missings or “do not know” for this variable may truly reflect a neutral point of view. Given these considerations, and for consistency, we decide to exclude the missings for each of the three dependent variables in main analysis. In sensitivity analysis, we then re-run the estimations using the full sample with mean imputation for each respective dependent variable.

Analytical approach

We begin with a bivariate analysis of how each of the three outcome variables correlates with financial knowledge. This helps determine if climate-related policy preferences differ across respondents with different literacy levels. To test the relationship between Big Three financial knowledge and attitudes toward climate fiscal policy, we use ordinary least squares (OLS) regressions following previous studies in the mainstream literature. The OLS models can be demonstrated as:

$$Y_i = \alpha_0 + \alpha_1 FinLit_i + \beta X_i + \epsilon_i \quad (1)$$

where Y_i denotes respondent i ’s attitude scale levels about perceptions of the carbon tax and whether the respondent supports using pension fund investment to address climate change. $FinLit_i$ represents the Big Three financial literacy score. α_0 is the intercept term, while α_1 is the effect of financial literacy on attitudes toward climate change policy to be estimated in the model. X_i is a vector of control variables including age, age-squared, sex, marital status, household size, employment, and household income, which have been used in the literature (Alessie et al., 2011; Fong, 2025; Grohmann, 2018; Koh et al., 2020; Niu et al., 2020; Van Rooij et al., 2011). ϵ_i is the error term.

However, using OLS models to estimate the impact of financial literacy on attitudes toward climate change policy may lead to biased

¹⁰ The CPF program is mandatory for residents who are in the workforce, has almost universal coverage, and requires contribution rates ranging from 37% of wages (17% by employers and 20% by employees) for working adults ages 55 and below, to 12.5% of wages for those above age 70. Contribution rates decline progressively from 37% to 12.5% over five age bands. Current regulations allow plan participants to invest their pension savings via the self-directed investment scheme even at older ages beyond age 55, as long as they have set aside a minimum retirement sum for mandatory annuitization; this was \$198,800 in 2023. (See <https://www.cpf.gov.sg/service/article/can-i-continue-to-invest-under-the-cpf-investment-schemes-beyond-age-55>). For further details about the CPF investment scheme, please see Fong (2020) and Fong and Mitchell (2025).

¹¹ The percentage of missings is 10.8% for the second outcome variable and 14.0% for the first outcome variable.

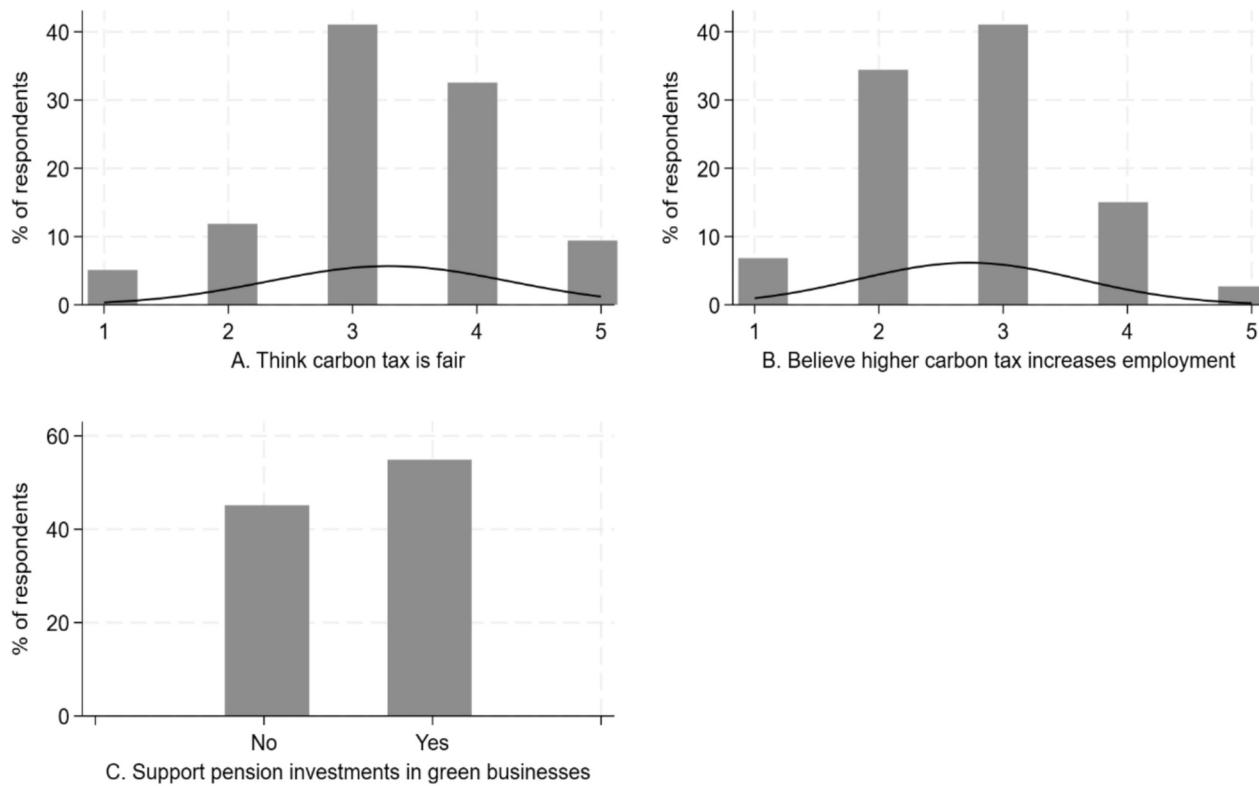


Fig. 2. Attitudes toward carbon tax policy in Singapore .

Source: Authors' own. Notes: Respondents with missing values are excluded so the percentages do not sum to 100%; see text. Sample is representative of the older demographic; no weights are applied

results if financial literacy itself is endogenous. For example, respondents who feel more strongly (whether in a positive or negative way) about climate fiscal policies may spend more time learning about the tax system and general monetary environment, and thus acquire financial know-how. In addition, there may be unobservable factors that can affect both their financial literacy and attitudes toward carbon tax policy. In this way, our OLS regression estimates can be biased. To address the potential endogeneity problem, we implement IV-GMM (Generalized Method of Moments) using the oldest siblings' financial situation as the instrumental variable. Sibling's financial situation is a suitable instrumental variable since it likely correlates with the respondent's financial knowledge levels but arguably not under the control of the respondents, and hence exogenous and uncorrelated with the respondents' observable characteristics. Furthermore, the relevance and validity of this instrument and relatedly, parental financial experience, has been documented in prior empirical investigations of financial literacy and financial behaviors in both Western countries (Bannier & Schwarz, 2018; Van Rooij et al., 2011) and Asian countries (Grohmann, 2018; Fong, 2025). Specifically, respondents are asked: "Would you say that your oldest brother or sister is in worse, better, or about the same financial condition as you? If no older sibling, can consider a younger sibling closest to your age", and their answers were coded in three categories (1 = No sibling or don't know, 2 = Worse, 3 = The same or better). The IV-GMM first stage regression can be demonstrated as:

$$FinLit_i = \gamma_0 + \gamma_1 Sibling_i + \delta X_i + \mu_i \quad (2)$$

where $FinLit_i$ represents financial literacy score. $Sibling_i$ represents the

siblings' financial situation, measured by two sets of dummy variables.¹² X_i is a vector of individual demographic and socioeconomic covariates as defined earlier. γ_0 is the intercept term, while γ_1 is the association between the IV and financial literacy to be estimated in the first stage regression model. μ_i is the error term. Finally, we check the robustness of our main findings by examining some extensions and alternative specifications of the multivariate climate-related policy preference regressions. All statistical analyses in this present study are conducted with Stata 18.0.

Results

Correlation between financial knowledge and outcomes

We first conduct a descriptive analysis of the relationship between financial literacy and the three outcome variables: (i) *think carbon tax is fair*, (ii) *believe higher carbon tax increases employment*, and (iii) *support pension investments in green businesses*. Fig. 3 shows the average scores of the first two outcome variables (continuous variables) by financial literacy score, as well as the percentage of respondents who provided affirmative responses to the third outcome variable (dichotomous variable). The trend lines indicate slight negative correlations between *think carbon tax is fair* and financial literacy, and separately, between *believe higher carbon tax increases employment* and financial literacy. The proportion of respondents who *support pension investments in green businesses* does not vary systematically with financial literacy, although the overall trend line indicates a somewhat positive correlation.

¹² The first dummy is "Worse" or "No siblings or don't know", the second dummy is "The same or better" or "No siblings or don't know".

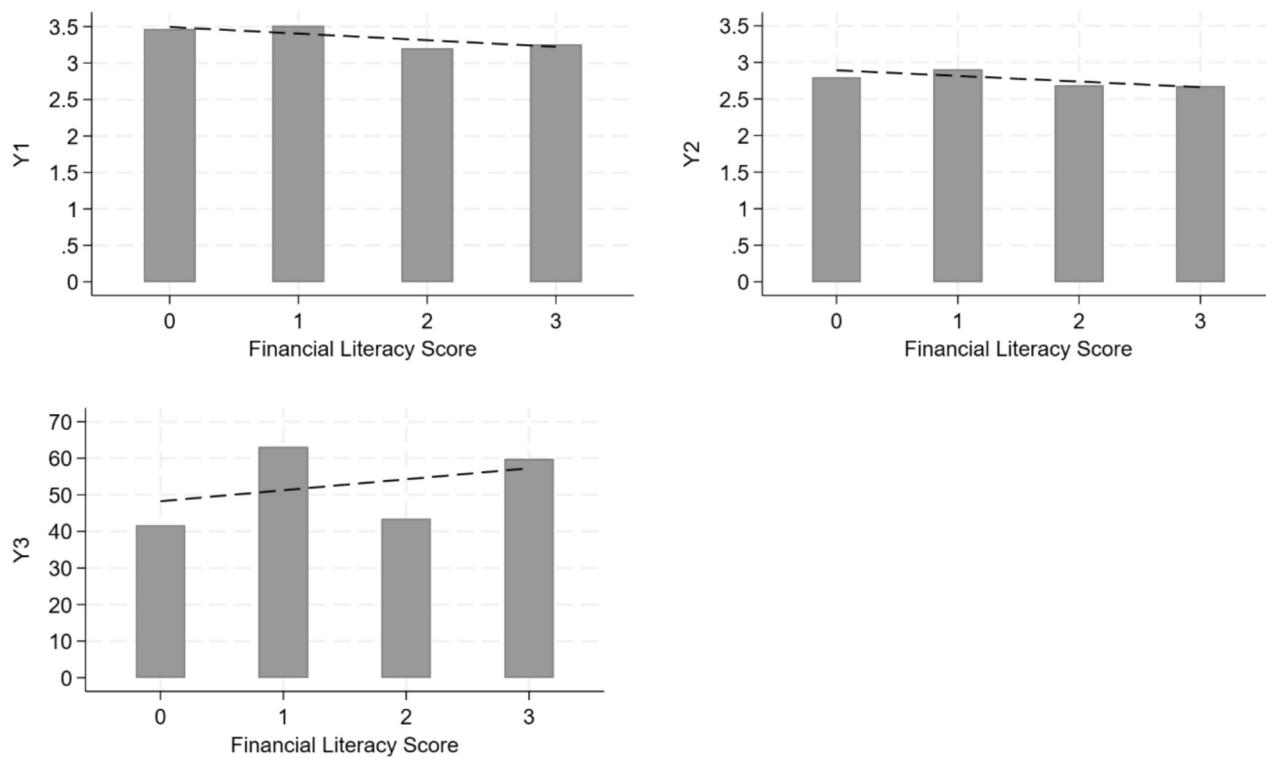


Fig. 3. Financial literacy score and attitudes toward carbon tax policy .

Source: Authors' own. Notes: Y1 = Average score of thinking carbon tax is fair. Y2 = Average score of believing higher carbon tax increases employment. Y3 = Percentage (%) of supporting pension investments in green businesses. Sample is representative of the older demographic; no weights are applied

Additionally, we conduct statistical tests (t-tests and Chi-square tests) to assess subgroup differences in attitudes towards climate fiscal policies.¹³ The results reveal that the gaps in scores for *think carbon tax is fair* and *believe higher carbon tax increases employment* over different financial literacy levels are significant, but the gap in proportions of respondents who *support pension investments in green businesses* is not significant.¹⁴ In sum, these non-regression tests suggest significant associations between financial literacy and thinking carbon tax is fair and believing high carbon tax increases employment, while the association between financial literacy and support for pension investments in green businesses is not significant.

Linear regression results

Table 2 presents the OLS regression results (coefficients and robust standard errors). The significant levels are 10 %, 5 %, and 1 %. Columns 1 and 2 of the Table show that financial literacy is negatively and significantly associated with *think carbon tax is fair* and *believe higher carbon tax increases employment*. Specifically, a one-unit increase in financial literacy score is associated with a 0.098 decrease in the *think carbon tax is fair* score ($p < 0.05$). Similarly, getting one more literacy question correct is associated with a 0.065 decrease in the *believe higher carbon tax increases employment* score ($p < 0.10$). However, Column 3

shows that financial literacy is not significantly associated with *support pension investments in green businesses*; the p -value of financial literacy's coefficient is above 0.10. This could be because most individuals in Singapore do not actively manage their pension investments. Most Singaporeans leave their pension accumulations in the default CPF fund to earn risk-free interest rates of 2.5 %–5% (Fong, 2020). These guaranteed rates of returns are fixed and do not vary with the financial markets.¹⁵ Consequently, any financial benefits (or losses) from green investments by the default CPF pension fund have no redistribution implications on pension plan participants.¹⁶

In terms of control variables, Table 2 shows that age, sex, marital status, household size, employment, household income level, and education predict respondents' attitudes toward climate fiscal policy. For instance, in Column 2, we see that age is significantly and positively associated with *believe higher carbon tax increases employment*. Age-squared is also statistically significant, suggesting that the association between age and support for carbon tax policy in this dataset is nonlinear. Women and married individuals generally have more positive attitudes towards carbon taxation. However, having a larger household size and being employed predict more negative attitudes toward climate fiscal policies in our data, which indicates that the burden of making a

¹³ We divide total sample into two groups based on their financial literacy scores: high literacy group (financial literacy score = 2 or 3) and low literacy group (financial literacy score = 0 or 1). Then we conduct t-test for differences in scores of thinking carbon tax is fair and believing high carbon tax increases employment and frequencies of supporting pension investments in green businesses over two financial literacy groups.

¹⁴ T-statistic for test on thinking carbon tax is fair is 3.352 ($p < 0.01$) and for believing high carbon tax increases employment is 2.868 ($p < 0.01$), the Chi-squared for test on supporting pension investments in green businesses is 0.688 ($p > 0.10$).

¹⁵ Monies in the default fund are aggregated and invested by the CPF Board in Special Singapore Government Securities (SSGS), which are issued specially by the Government to the CPF Board. The coupon rates on these SSGS are pegged to the CPF interest rates that members receive and vary by type of CPF sub-account. For example, the interest rate for Ordinary Account is 2.5–3.5% per annum, while the interest rate for MediSave Account is slightly higher at 4–5% per annum. Since the Singapore Government is triple-A credit-rated, returns from investing via the default CPF fund are considered "guaranteed" and "risk-free" (Fong, 2020).

¹⁶ Social policies which involve redistribution among groups of individuals in society are more likely to have influence individuals' attitudes and preferences towards such policies (Montagnoli et al., 2017).

Table 2

Financial literacy and attitudes toward carbon tax policy (OLS estimations).

	(1) Think carbon tax is fair Coefficient (SE)	(2) Believe higher carbon tax increases employment Coefficient (SE)	(3) Support pension investments in green businesses Coefficient (SE)
Financial literacy	-0.098** (0.039)	-0.065* (0.035)	0.006 (0.019)
Age (years)	-0.068 (0.068)	0.158** (0.064)	-0.050 (0.034)
Age ²	0.001 (0.001)	-1.119e ⁻³ ** (4.745e ⁻⁴)	4.059e ⁻⁴ * (2.460e ⁻⁴)
University or above	-0.075 (0.076)	0.024 (0.070)	0.136*** (0.039)
Female	0.165** (0.064)	-0.011 (0.059)	0.120*** (0.035)
Married	0.351*** (0.078)	0.131* (0.070)	0.239*** (0.040)
Larger household size	-0.195** (0.078)	-0.017 (0.076)	-0.096** (0.042)
Employed	-0.107 (0.080)	-0.076 (0.072)	-0.075* (0.041)
Household income (ref = <\$5,000)			
\$5,000 and <\$10,000	0.427*** (0.101)	0.028 (0.087)	0.271*** (0.054)
\$10,000 and <\$15,000	0.567*** (0.099)	0.140 (0.086)	0.285*** (0.052)
≥\$15,000	0.717*** (0.106)	0.490** (0.103)	0.238*** (0.059)
Prefer not to say	0.888*** (0.275)	0.344 (0.286)	0.292* (0.175)
R-squared	0.108	0.059	0.146
Observations	860	892	800

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors are in parentheses. Sample is representative of the older demographic; no weights are applied.

living reduces support for measures mitigating climate change. In addition, higher income predicts more positive attitudes toward climate fiscal policies, suggesting that wealthy people are more willing to accept the costs of climate fiscal policies than less wealthy ones. In terms of education, Column 3 of the Table shows that educational attainment is positively related to *support pension investments in green businesses*, although it is unrelated to the other two outcomes on fairness and employment opportunities. A possible reason is that assessing the benefits of green investment involves certain levels of business knowledge, but assessing the impact on fairness and employment is more straightforward.

Instrumental variable regression results

Based on the OLS results, we proceed with IV analysis only for the first and second outcomes, namely *think carbon tax is fair* and *believe higher carbon tax increases employment*. Table 3 reports the IV-GMM estimation results using the oldest sibling's financial situation as an instrument for the respondents' financial literacy. We find that, even after instrumentation, the impact of financial literacy on both variables remains negative and statistically significant (both $p < 0.05$). Specifically, a one-unit increase in the Big Three financial literacy score is associated with a 0.596 decrease in the *think carbon tax is fair* score and a 0.518 decrease in the *believe higher carbon tax increases employment* score. In line with the literature, these instrumented literacy estimates are larger than those from our OLS analysis, which echoes the observation from

Table 3

Financial literacy and attitudes toward carbon tax policy (IV-GMM estimations).

	(1) Think carbon tax is fair Coefficient (SE)	(2) Believe higher carbon tax increases employment Coefficient (SE)
Financial literacy	-0.596** (0.279)	-0.518** (0.222)
Age (years)	-0.098 (0.073)	0.125* (0.073)
Age ²	0.001 (0.001)	-0.001 (0.001)
University or above	-0.052 (0.080)	0.076 (0.081)
Female	0.114 (0.076)	-0.054 (0.068)
Married	0.333*** (0.086)	0.108 (0.080)
Larger household size	-0.064 (0.113)	0.073 (0.097)
Employed	-0.162* (0.091)	-0.095 (0.080)
Household income (ref = <\$5,000)		
\$5,000 and <\$10,000	0.596*** (0.148)	0.242* (0.142)
\$10,000 and <\$15,000	0.651*** (0.124)	0.266* (0.117)
≥\$15,000	0.670*** (0.124)	0.516*** (0.112)
Prefer not to say	1.075*** (0.387)	0.479* (0.252)
Exogeneity test		
GMM C: p-value	0.038	0.019
First-stage regression		
F-statistic	13.40	15.35
Over identification		
Hansen's J: p-value	0.794	0.272
Observations	860	892

Notes: Robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Sample is representative of the older demographic; no weights are applied.

prior studies that OLS analyses underestimate the true effect of financial literacy (Lusardi & Mitchell, 2014; Van Rooij et al., 2011).

We are attentive to the potential problems caused by weak instruments. However, in our estimations, the first-stage F-statistics are 13.04 in Column 1 and 15.35 in Column 2, respectively (see bottom of Table 3). These values exceed the commonly-used threshold of 10 for weak-strong IV test, thus allaying concerns about weak instruments. Moreover, the p-values of the GMM C statistic for exogeneity test reject the null hypothesis that financial literacy is exogenous in both cases. In other words, financial literacy is endogenous for the outcome variables examined and the IV approach is warranted for each respective case. Furthermore, diagnostic checks using the Hansen J-test indicate no rejection of the over-identifying restrictions, supporting the instrument's validity in each case. The first-stage regression results (Appendix Table A4) confirm that the oldest sibling's financial situation is statistically significantly linked to financial literacy scores (p -value is < 0.01). This helps further validate the choice of our instrument for respondents' financial literacy. In sum, our OLS and IV-GMM estimation results indicate that financially savvy older adults are generally less supportive of climate fiscal policies in that they are less likely to perceive carbon tax as fair and believe that increasing the carbon tax will help increase employment. Importantly, these effects are causal. The impact of financial literacy on climate-related policy preferences, however, does not extend to individuals' considerations about pension investments in green businesses.

Robustness checks and extensions

In this section, we conduct additional analyses to ascertain the robustness of our main empirical findings. First, we examine some alternative specifications of the multivariate regressions, incorporating extensions that account for potential common unobserved factors. Second, we perform sensitivity analyses using an alternative measure of financial literacy based on three separate indicator variables, in lieu of the cumulative literacy score. Third, we evaluate whether the impact of financial knowledge on climate-related attitudes varies between males and females. We also perform heterogeneity analysis by income groups and education. Finally, to check that the exclusion of missing values for the dependent variables did not substantively affect the main findings, we repeat the IV-GMM estimations using the full sample with mean imputation for missing values.

Alternative empirical specifications

Previous research suggests that cultural differences may influence attitudes toward carbon tax policy. For instance, [Stoutenborough et al. \(2014\)](#) find that Asian and Black individuals in the United States are less supportive of policy solutions to mitigate climate change. This is also pertinent to our context since Singapore is a multi-racial and multi-ethnic society. Aside from Chinese Singaporeans who form the bulk of the total population, the resident population also comprises those who are ethnic Malay, ethnic Indian, and others (e.g., Eurasian). Certain communities, given their cultural upbringing, could be more likely to support carbon fiscal policies and to invest in financial education.¹⁷ Accordingly, we control additionally for race/ethnicity and test whether the causal impact of financial literacy on the first two outcomes remains robust. We find that the inclusion of race/ethnicity dummy variables in our multivariate regressions does not take away the effect of financial knowledge on *think carbon tax is fair* and *believe higher carbon tax increases employment* (see [Table 4](#)). For instance, based on the instrumented estimates, a one-unit increase in financial literacy score results in a 0.580 decrease ($p < 0.05$) in the *think carbon tax is fair* score. Compared to ethnic Chinese, Singaporeans of other ethnicities are more inclined to think that a *carbon tax is fair*, but less inclined to believe that an increase in the *carbon tax increases employment*.¹⁸

Another possible common trait that has not been taken into account in the main analysis is risk preferences. Individuals with greater preference for risk may be both more likely to acquire financial literacy and find that carbon taxes make good economic sense since such taxes correct a market failure and make the economy more efficient. It is not clear, however, how risk preferences may correlate with support for carbon taxes *a priori* given mixed empirical evidence on this front. [Vilalacis et al. \(2021\)](#) found that general risk preference is negatively associated with individuals' expectations of climate change in Latin America, while [Hasanaj and Stadelmann-Steffen \(2022\)](#) find a positive association between climate-related risk perception and support for carbon tax policy in the United States. Our dataset contains a direct measure of risk preference based on a "coin toss" question that has been well-documented in the literature ([Coombs & Meyer, 1969](#)). Specifically, respondents are asked to choose between two hypothetical scenarios: either (a) get \$50 for sure, or (b) toss a coin: get \$100 or \$0 for 50–50 chance. Respondents who cannot decide may also state no

¹⁷ In 2023, the ratio of ethnic Chinese to others in the Singaporean resident population is 74:26 ([Department of Statistics of Singapore, 2024](#)). In our sample, the distribution of respondents by race/ethnicity is 76:24, which mirrors the resident population profile. All ethnic groups share a common Singaporean identity. Cultural upbringing refers to the socialization process in which an individual is raised within a specific cultural group, acquiring its norms, values, customs, and traditions.

¹⁸ Detailed results from all analyses in this section are available upon request.

preference. We construct a binary variable for high risk tolerance set to 1 if the respondent chose "toss a coin", and 0 otherwise.¹⁹ As [Table 4](#) illustrates, we find that both the OLS and IV-GMM estimates of the Big Three financial literacy score are not affected by the inclusion of this variable. Furthermore, our estimates show that risk preference is not significantly associated with either outcome variable.

Past research has shown that revenue uses, prior knowledge, and information provision about the functioning of carbon taxation can affect policy perceptions and acceptability of carbon taxation ([Maestre-Andrés et al., 2021](#); [Drew et al. 2022](#)). In Spain, for instance, citizens show favorable attitudes to a carbon tax with revenues used to compensate COVID-19-related expenditures ([Drews et al., 2022](#)). Individuals with higher assessed prior knowledge may also have higher climate concern and prefer to spend money on climate projects ([Maestre-Andrés et al., 2021](#)). Our survey in Singapore contains a question that assesses respondents' prior knowledge about carbon taxation in Singapore. Specifically, survey participants are asked "Do you know if there is a carbon tax in Singapore?" This question is asked before we provide a preamble on when the carbon tax was first introduced in the city-state and how implemented. Accordingly, we create a binary variable for policy awareness that is set to 1 if the respondent answered "yes" to the question, and 0 otherwise. Empirical estimates show that the inclusion of this control variable did not alter our main result concerning the negative impact of financial literacy on carbon tax acceptance; see [Table 4](#). As expected, policy awareness is positively associated with both our outcome variables.

Another potential confounder that has been omitted thus far in our analysis is climate change concern. Prior research has demonstrated that values of climate concern are predictive of carbon tax acceptance among households ([Drews et al., 2022](#)). In Turkey, for instance, individuals concerned with climate change feel greater necessity to address this challenge and express more positive attitudes toward climate policies ([Uyduranoglu & Ozturk, 2020](#)). Our data do not contain a direct measure for climate change concern. Nonetheless, we did solicit people's views on climate change by asking respondents "Which comes closer to your own view on climate change?" Responses include (1) Most scientists think climate change is not happening; (2) There is a lot of disagreement among scientists about whether or not climate change is happening; and (3) Most scientists think climate change is happening. We construct a categorical variable based on these responses and use it in a separate robustness check. As shown in the last two columns of [Table 4](#), we find that both the OLS and IV-GMM estimates of the Big Three financial literacy score are not affected by the inclusion of this variable. Furthermore, our estimates show that individuals who believe climate change is happening are more likely to support carbon taxation compared to their peers who do not believe or have mixed attitudes.

Alternative measure of Big Three financial literacy

As noted earlier in the breakdown of responses by question, the proportion of correct answers varies across the Big Three questions. 88 % of respondents correctly answered the interest rate question, 70.7 % correctly answered the inflation question, and only 57.3 % correctly answered the risk diversification question (see [Appendix Table A3](#)). Accordingly, we re-run the main analysis using three disaggregated indicator variables for financial literacy in lieu of the cumulative Big Three score. Results are summarized in [Table 5](#). Two conclusions are noteworthy. First, all three literacy variables are significantly associated with *support pension investments in green businesses*, but the direction of the effects is non-uniform. As shown in the last column of the Table, interest rate literacy and risk diversification literacy are positively related to the outcome, which suggests that older adults who understand such financial concepts are more likely to support allocation of pension

¹⁹ About 21% of respondents chose "toss a coin" (see [Table 1](#)).

Table 4
Robustness checks with additional control variables.

	Additional control: race/ethnicity		Additional control: risk tolerance		Additional control: policy awareness		Additional control: climate concern	
	(1) Think carbon tax is fair	(2) Believe tax increases employment	(1) Think carbon tax is fair	(2) Believe tax increases employment	(1) Think carbon tax is fair	(2) Believe tax increases employment	(1) Think carbon tax is fair	(2) Believe tax increases employment
Financial literacy: non-instrumented	Coefficient (SE) −0.086** (0.039)	Coefficient (SE) −0.070** (0.035)	Coefficient (SE) −0.098** (0.039)	Coefficient (SE) −0.065* (0.035)	Coefficient (SE) −0.119*** (0.038)	Coefficient (SE) −0.080** (0.036)	Coefficient (SE) −0.109*** (0.039)	Coefficient (SE) −0.082** (0.036)
Financial literacy: instrumented	−0.580** (0.288)	−0.548** (0.228)	−0.591** (0.275)	−0.521** (0.221)	−0.675** (0.029)	−0.559** (0.226)	−0.574** (0.270)	−0.568** (0.225)
Standard controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exogeneity test								
GMM C: p-value	0.047	0.015	0.038	0.018	0.003	0.014	0.052	0.011
First-stage regression								
F-statistic	12.702	14.931	13.586	15.478	12.894	14.727	14.120	16.034
Over identification								
Hansen's J: p-value	0.756	0.306	0.815	0.269	0.749	0.253	0.953	0.460
Observations	860	892	860	892	860	892	860	892

Note: Robust standard errors are in parentheses. The dependent variables are: (1) = Think carbon tax is fair. (2) = Believe higher carbon tax increases employment. Standard control variables include age, age², education, gender, marital status, household size, employment, and household monthly income. Instrumental variable is the oldest sibling's financial situation (no sibling or don't know, worse, the same or better). Variables are described in Appendix Table A1. **p* < 0.10, ***p* < 0.05, ****p* < 0.01. Sample is representative of the older demographic; no weights are applied.

Table 5
Robustness checks with alternative specifications of financial literacy.

	(1)		(2)		(3)	
	Think carbon tax is fair		Believe tax increases employment		Support pension investments in green businesses	
Big Three questions	Coefficient (SE)		Coefficient (SE)		Coefficient (SE)	
Interest rate	0.045 (0.129)		−0.029 (0.120)		0.116** (0.059)	
Inflation	−0.268*** (0.082)		−0.163** (0.082)		−0.197*** (0.041)	
Risk diversification	−0.001 (0.074)		0.012 (0.069)		0.147*** (0.038)	
Standard controls	Yes		Yes		Yes	
Observations	860		892		800	

Notes: Robust standard errors are in parentheses. Standard control variables include age, age², education, gender, marital status, household size, employment, and household monthly income. Variables are described in Appendix Table A1, and financial literacy questions are described in Appendix Table A3. **p* < 0.10, ***p* < 0.05, ****p* < 0.01. Sample is representative of the older demographic; no weights are applied.

assets in eco-friendly businesses. In contrast, inflation literacy is negatively associated with the outcome. These opposing literacy effects help explain why the cumulative Big Three score was not predictive of the third outcome in the main analysis.

Second, we find that inflation literacy has strong, negative associations with all three outcomes examined. In fact, it is the only financial literacy variable predictive of *think carbon tax is fair* and *believe higher carbon tax increases employment*; the interest rate and diversification variables are not statistically significant. Inflation literacy is also negatively and significantly associated with *support pension investments in green businesses*. This suggests that the key driver underlying the negative observed relationship between financial literacy and support for climate fiscal policies in the main analysis is people's understanding of inflation. Financially savvy persons who are more knowledgeable about inflation, and possibly its economic consequences, are more likely to oppose carbon taxation policies as these constitute an additional financial burden in people's day-to-day life. We conduct additional regression analysis and find that income, household size, and marital status are key determinants of inflation literacy in our data (see Table A5 of the Online Appendix). Another configuration of the Big Three

measure that has been used in the literature is an indicator variable for answering all three literacy questions correctly (or "all three correct"). While this is a useful measure to explore in a context where researchers seek to differentiate those who are financially literate from those who are not (e.g., Lusardi & Mitchell, 2014), this measure is inherently less informative than the cumulative Big Three score and has low applicability in Singapore's context where one in two persons get all three questions correct.²⁰

Heterogeneity analysis by sex, income, and education subgroups

We further conduct heterogeneity analysis to test if the impact of financial literacy on attitudes toward carbon tax policy varies across sex, income, and education subgroups. As Panel A of Table 6 shows, more

²⁰ In our sample, 47.2% of respondents answered all three questions correctly, which consistent with the 49.2% documented in Fong (2025) for Singapore's national financial literacy survey. The proportion of "all three correct" range from about 24.0 to 53.2 in developed economies (Fong, 2025).

Table 6

Summary of results from heterogeneity analysis.

Panel A: Heterogeneity analysis by sex

	Male		Female	
	(1) Think carbon tax is fair Coefficient (SE)	(2) Believe tax increases employment Coefficient (SE)	(1) Think carbon tax is fair Coefficient (SE)	(2) Believe tax increases employment Coefficient (SE)
Financial literacy: non-instrumented	-0.146*** (0.054)	-0.083 (0.052)	-0.039 (0.058)	-0.032 (0.048)
Financial literacy: instrumented	-0.445* (0.267)	-0.024 (0.206)	-0.699 (0.648)	-1.479* (0.792)
Exogeneity test				
GMM C: <i>p</i> -value	0.237	0.790	0.212	0.001
First-stage regression				
F-statistic	12.168	13.824	2.885	3.371
Over identification				
Hansen's <i>J</i> : <i>p</i> -value	0.561	0.234	0.404	0.698
Observations	435	446	425	446

Panel B: Heterogeneity analysis by household monthly income

	Household income < \$10,000		Household income ≥ \$10,000	
	(1) Think carbon tax is fair Coefficient (SE)	(2) Believe tax increases employment Coefficient (SE)	(1) Think carbon tax is fair Coefficient (SE)	(2) Believe tax increases employment Coefficient (SE)
Financial literacy: non-instrumented	0.067 (0.057)	-0.023 (0.050)	-0.224*** (0.050)	-0.076 (0.051)
Financial literacy: instrumented	-0.258 (0.419)	-0.507 (0.354)	-0.422 (0.289)	-0.365 (0.258)
Exogeneity test				
GMM C: <i>p</i> -value	0.413	0.145	0.494	0.230
First-stage regression				
F-statistic	3.257	4.349	17.720	20.420
Over identification				
Hansen's <i>J</i> : <i>p</i> -value	0.182	0.433	0.080	0.253
Observations	411	435	437	444

Panel C: Heterogeneity analysis by educational attainment

	Non-tertiary		University or above	
	(1) Think carbon tax is fair Coefficient (SE)	(2) Believe tax increases employment Coefficient (SE)	(1) Think carbon tax is fair Coefficient (SE)	(2) Believe tax increases employment Coefficient (SE)
Financial literacy: non-instrumented	-0.034 (0.047)	-0.113*** (0.041)	-0.219*** (0.073)	0.081 (0.066)
Financial literacy: instrumented	-0.278 (0.244)	-0.328 (0.204)	-1.664 (1.140)	-0.726 (0.691)
Exogeneity test				
GMM C: <i>p</i> -value	0.284	0.257	0.052	0.067
First-stage regression				
F-statistic	13.699	15.477	1.668	2.362
Over identification				
Hansen's <i>J</i> : <i>p</i> -value	0.930	0.369	0.728	0.098
Observations	623	654	237	238

Note: Robust standard errors are in parentheses. Instrumental variable is the oldest sibling's financial situation (no sibling or don't know, worse, the same or better). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

financially savvy males are less likely to agree that *carbon tax is fair* while more financially literate females are less likely to believe *carbon tax increases employment*. These gender differences may be linked to the roles of men and women in Asian societies. Although both male and female Singaporeans receive equal education opportunities, the labor force participation rate has been persistently lower for females than males.²¹ In many households, males are the main breadwinners. Financially literate men, in particular, may be more wary of the financial burden of carbon taxes (or increases in such taxes) on personal and household finances, which contribute to their negative views on the

fairness and equity of such policies.

Panel B of Table 6 indicates that the negative influence of financial literacy on *think carbon tax is fair* is attributable mostly to respondents with a monthly household income of at least S\$10,000, rather than those with lower monthly household income.²² This may be because high-income persons who are financially literate are more acutely aware that higher-income households tend to have higher average energy consumption (Zheng et al., 2024). Finally, Panel C shows that the financial literacy effect on *think carbon tax is fair* is only statistically significant for tertiary-educated respondents, while the financial literacy

²¹ In 2023, the labor force participation rate is 76.2% for males and 61.6% for females (Department of Statistics of Singapore, 2024).

²² A S\$10,000 income threshold is suitable since the median of Singaporean household monthly income is \$10,869 in 2023 (Department of Statistics of Singapore, 2024).

effect on *believe higher carbon tax increases employment* is only statistically significant for those with less formal education. A possible reason is that more educated people enjoy higher employment stability (Cairó & Cajner, 2018), and are thus less concerned about the employment implications of climate fiscal policies.

Estimations using the full sample with imputation for dependent variables

In the main regression analysis, we excluded respondents with missing values for the dependent variables. Nonetheless, these non-responses constitute about 10–14 % of the overall sample and there may possibly be a non-response bias (Crossley et al., 2021). To check that the exclusion of respondents with non-responses did not substantively affect the main findings, we repeat the IV-GMM estimations using the full sample ($N = 1000$) with mean imputation for missing values. Table 7 reports the empirical results. We find that the negative effect of financial literacy on *think carbon tax is fair* and *believe higher carbon tax increases employment* remains statistically significant (both still $p < 0.05$), although the magnitude of the effects attenuated slightly. For instance, a one-unit increase in Big Three financial literacy decreases the *think carbon tax is fair* score by 0.447 (compare 0.596 in main analysis). There is no weak instrument problem; the first stage F-statistic using full sample is 17.88 and 18.88 for each respective outcome. Finally, the first-

Table 7
Robustness check with full sample (IV-GMM estimation).

	(1) Think carbon tax is fair Coefficient (SE)	(2) Believe higher carbon tax increases employment Coefficient (SE)
Financial literacy	-0.469** (0.205)	-0.424** (0.178)
Age (years)	-0.110* (0.062)	0.110* (0.063)
Age ² (years ²)	0.001** (4.609e ⁻⁴)	-0.001 (4.684e ⁻⁴)
University or above	-0.015 (0.074)	0.076 (0.073)
Female	0.114* (0.064)	-0.055 (0.060)
Married	0.252*** (0.073)	0.082 (0.070)
Larger household size	-0.100 (0.075)	0.018 (0.074)
Employed	-0.087 (0.072)	-0.066 (0.069)
Household income (ref = <\$5,000)		
\$5,000 and <\$10,000	0.495*** (0.131)	0.222* (0.124)
\$10,000 and <\$15,000	0.559*** (0.114)	0.272** (0.108)
≥\$15,000	0.602*** (0.097)	0.523*** (0.103)
Prefer not to say	0.832*** (0.298)	0.470** (0.224)
Dummy for non-responses	-0.205* (0.103)	-0.060 (0.078)
Endogeneity test		
GMM C statistic p value	0.038	0.017
First-stage regression		
F-statistic	17.91	18.88
Over identification		
Hansen's J statistic p value	0.905	0.251
Observations	1,000	1,000

Note: Robust standard errors are in parentheses. Mean imputation is used for missing values (non-responses) for each dependent variable. A dummy variable indicating non-responses is also added to the regressions. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Sample is representative of the older demographic; no weights are applied.

stage regression results confirm that the oldest sibling's financial situation is statistically significantly linked to financial literacy scores (p -value is < 0.01).

Discussion and conclusion

This paper has explored the impact of various key factors driving older adults' attitudes towards climate fiscal policies and carbon taxation in an aging society, with a particular focus on financial literacy. We find that older persons with higher financial literacy are generally less supportive of climate fiscal policies in that they are less likely to perceive carbon tax as fair and less likely to believe that increasing carbon tax will help increase employment, controlling for a host of sociodemographic covariates. Importantly, these relationships are causal. Financial knowledge results in lower support for carbon taxes, and not the other way around (i.e., a situation where persons with negative views of carbon taxes spend more time and effort to acquire financial knowledge). Our findings are also robust to various empirical variations. Nonetheless, financial knowledge does not necessarily correlate with all types of climate-related policy preferences. Specifically, we do not evidence a correlation between the financial literacy score and individuals' support for pension investments in green businesses, controlling for potential confounders. To the best of our knowledge, this is the first study to evaluate the causal relationship between Big Three financial literacy and attitudes towards carbon taxation in a nationally representative sample of older adults.

In addition to financial literacy, personal factors such as marital status, income, and age affect older adults' views on whether a carbon tax is fair and their beliefs on whether a higher carbon tax may increase employment. Married older adults are also more likely to think that a carbon tax is fair. Household income is associated with positive attitudes toward climate fiscal policies: wealthier older persons are not only more inclined to agree that a carbon tax is equitable as compared to their less wealthy counterparts, but also more likely to agree that increasing carbon taxes can increase job opportunities and employment. There is also some suggestion that persons at very advanced ages are more likely to believe that a hike in carbon tax helps boost employment, though the age effect is small. Our empirical results are broadly in line with the literature. For example, studies focusing on policy preferences towards climate fiscal policies have reported that higher income earners tend to be more supportive of carbon taxes (Fairbrother et al., 2019; Kallbekken et al., 2013), since wealthier households tend to spend a smaller share of their income on carbon-intensive goods as compared to poorer households.

Our main finding that financial literacy has a negative causal effect on older adults' attitudes towards carbon taxes may seem counterintuitive at first glance. In particular, one may instead expect financially savvy individuals to better appreciate the efficacy of carbon taxation as a policy instrument to discourage carbon consumption and lower the risks of catastrophic climate changes in society—a point of view expounded by many economists and some international organizations (Mankiw, 2009; Baranzini et al., 2017; World Bank, 2024). We attempt to address this aspect in additional analysis by using disaggregated financial literacy indicators that capture the heterogeneity in responses across the Big Three questions. Interestingly, our results show that a primary driver underlying the negative relationship between financial knowledge and carbon taxation attitudes is people's understanding of inflation (or inflation literacy). This finding holds across all three attitudinal outcomes examined in our study. This is reasonable when analyzed from a consumer viewpoint: individuals who are knowledgeable about inflation may be more cognizant about its perceived causes and consequences, including the fact that carbon pricing can lead to higher costs of production and costs of living, and hence less supportive of carbon taxation. Indeed, local media reports have documented that Singapore has been seeing sustained increases in electricity and gas tariffs in recent years, with households facing a combination of the direct and indirect effects

of the carbon tax (Tan, 2022). Older cohorts of Singaporeans, including our survey respondents who are born in the 1930 s-1960 s, are potentially more sensitive to such inflationary pressures having experienced in their younger days the “tumultuous seventies” which was a period of high and volatile inflation due to the global oil crises (Monetary Authority of Singapore, 2025).²³

Under Singapore’s carbon tax policy, business facilities such as oil refineries and power generation plants that produce an annual total amount of reckonable Greenhouse Gas emissions with a carbon dioxide equivalence of 25,000 tCO₂e or more are liable to pay carbon tax. Power generation companies that are levied the carbon tax pass on some of the cost to electricity retailers like SP Group, which in turn, pass on these additional costs to end-customers. In September 2023, for instance, state energy suppliers in Singapore jointly announced an increase in power tariffs.²⁴ Household electricity and gas bills rose subsequently. Aside from such direct effects, indirect effects of the carbon tax on household expenditure may include, for instance, an increase in the costs of eating out as restaurants increase food prices given their own utility bills increase. The impact of such cost increases will be more acute for older adults who rely on their savings and pensions, as compared to working age adults. These concerns, coupled with the high inflation in Singapore and globally over 2022 and 2023, thus rationalize our key finding of a negative relationship between Big Three financial literacy and pro-environmental attitudes in our data. Overall, our study provides new evidence supporting the notion that financial knowledge is linked to public decisions, thus adding to the new and growing literature in this field (e.g., Fornero & Lo Prete, 2019, 2023).

Our study provides important implications for policymakers and administrators. As the populace becomes more educated and more financially literate, this may culminate in a larger proportion of residents being less supportive of carbon taxation and climate fiscal policies. Accordingly, efforts to cushion the impact of carbon tax charges on end-consumers and households can go a long way in helping alleviate some of these negative attitudes. For instance, the Singaporean government launched the Climate Friendly Households Programme in 2020 to encourage households to take climate actions to be more efficient in their energy and water consumption, while saving on utility bills in the long run. Vouchers were provided to eligible households to offset the purchase of various energy- and water-efficient appliances and fittings. The programme initially targeted lower-income households living in smaller dwelling types but was enhanced in 2024 to benefit a large cross-section of Singaporean households (ChannelNewsAsia, 2024). Also, the government assists lower- to middle-income Singaporean households with their utility bills payment through the Utilities-Save (U-Save) scheme regardless of which electricity retailer a household subscribes to. Higher amounts of U-save rebates are allocated to lower-income households. As societies continue to age and become more financially literate, policymakers in other countries who are looking to introduce (or increase) carbon taxation should consider accompanying policy interventions to help cushion the carbon tax impact on end-consumers and small businesses. For example, carbon revenues can be used to cushion the consumer impact.

²³ During the 1970s, Singapore experienced high and volatile inflation, driven by the global oil crises of 1973 and 1979. Specifically, global oil prices quadrupled in 1973 after the Organisation of the Petroleum Exporting Countries imposed an embargo against the United States. Higher global oil prices led to cost-push inflation, driving Singapore’s headline inflation to as high as 30% in the first half of 1974, compared to the same period the year before.

²⁴ In the fourth quarter of 2023, the electricity tariff before the goods and services tax went up by an average of 3.7 per cent or 0.98 Singapore cent per kilowatt-hour (KWh) from the previous quarter. This means the electricity tariff before goods and services tax will increase to 28.7 cents per KWh from 27.74 cents in Q3 of 2023. For a typical household in Singapore, this translates to an average increase in monthly electricity bill by about 3.5% (Tay, 2023).

Our empirical findings also have implications for educational programs. The fact that financial literacy shapes people’s views on carbon taxation and climate-related policy preferences (albeit not in the anticipated direction) implies that financial knowledge has a broader impact on people’s decision-making than previously documented in the literature. Accordingly, a key avenue to boost financial literacy among individuals and households is through financial education programs. For example, many US states have mandated financial literacy in high schools and many employers offer workplace financial education via benefit fairs (Kaiser et al., 2022). In a *meta-analysis* covering more than 30 countries, Kaiser et al. (2022) showed that financial education programs generally have positive causal effects on financial knowledge and downstream financial behaviors. Also important is the need to promote and strengthen environmental literacy in the population. According to Hollweg et al. (2011), environmental literacy is defined as “knowledge of environmental concepts and issues; the attitudinal dispositions, motivation, cognitive abilities, and skills, and the confidence and appropriate behaviors to apply such knowledge in order to make effective decisions in a range of environmental contexts.” In many countries, environmental or climate literacy programmes currently take place in schools (e.g., Earth Day student projects), as well as in workplaces (e.g., ESG training for employees). Our study suggests that communication campaigns on climate change and carbon taxation directed towards older demographic groups are urgently warranted. For example, climate literacy programmes can be introduced to older persons through traditional media or through outreach at senior activity centres in communities and neighborhoods. As environmental and sustainability-related issues become increasingly complex, the need for both financial literacy and environmental literacy increases in importance.

This study has several limitations. First, older adults are disproportionately more vulnerable to climate change risks and less likely to support climate change mitigation policies compared to younger groups (Andor et al., 2018). As this study focuses on individuals aged 55 and over, our findings cannot be easily applied to other age groups. Second, given data limitations, this study does not control for individuals’ personal experience of climate events or the economy-level factors. Prior studies (e.g., Hoffmann et al., 2022) have demonstrated that experiencing extreme climate events like heat and drought may influence individuals’ attitudes toward climate fiscal policies (Harring et al., 2019). As Singapore has one of the highest levels of fossil fuel dependency in the world, caution is needed when applying our findings to other countries with lower levels of fossil fuel dependency. Future studies with more comprehensive datasets featuring a larger cross-section of the population can seek to address these limitations. Future research can also collate information on people’s participation in climate-related programs, and climate change adaptation, to undertake a broader analysis.

CRediT authorship contribution statement

Joelle H. Fong: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Yuhao Ba:** Writing – review & editing, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Zhe Chen:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jeoa.2025.100595>.

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