Temperature Shocks and Household Savings[♣]

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Abstract

We present the first study to examine the impact of temperature shocks on household savings behaviour. We first develop a theoretical model to examine the relationship between average temperature and savings via risk and time preferences. The model predicts an ambiguous effect of both risk and time preferences as channels. We test the theoretical predictions using longitudinal data from the Household, Income and Labour Dynamics in Australia Survey and satellite re-analysis temperature data. We find that a standard deviation increase in average temperature is associated with a 4.3% increase in net worth and a 12.8% increase in savings. We examine risk preferences and time preferences as channels and find that time preferences mediate the relationship between temperature shocks and savings.

Keywords: temperature, weather, preferences, savings, net worth, wealth accumulation

JEL: Q51, Q54, G02, G11, D14, E21

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1. Introduction

There is large variation across households with respect to savings and accumulated wealth, which cannot be explained by socioeconomic factors or asset allocation choices alone (Venti & Wise, 1998). To understand why individuals and households differ with respect to their savings behaviour, a growing body of literature has explored myriad factors and utilised various empirical and theoretical approaches to examine savings behaviour.[1] This literature has explored factors such as genetics, personality traits, demographics, behavioural factors, peer and parental influence, education and psychological factors, among others (see, e.g., Bernheim et al., 2001; Bisin & Verdier, 2001; Cobb-Clark et al., 2016; Cronqvist & Siegel, 2015; Harris et al., 2002; Lunt & Livingstone, 1991; Madrian & Shea, 2001; Nwosu et al., 2020).

We add to these studies by asking what is the impact of temperature shocks on savings?[2] We present a simple theoretical model that examines how extreme changes in temperature influence savings via risk and time preferences. To test the predictions from the theoretical model, we use longitudinal data from the Household, Income and Labour Dynamics in Australia (HILDA) Survey, which we merge with ERA5 satellite reanalysis data on temperature taken from the European Centre for Medium Range Weather Forecasts (ECMWF) at the postcode level.[3] We define temperature shocks for a given postcode and time as the deviation of actual temperature from the historical mean (see, e.g., Graff Zivin et al., 2020; Hirvonen, 2016; Letta et al., 2018). We measure household wealth and savings in HILDA as household total net worth derived from detailed information on household assets and liabilities (Cobb-Clark et al., 2016; Heady, 2003). In addition to total net worth, we consider financial and non-financial assets, and a measure of the household savings rate, defined as the difference in household wealth over time as share of income. We find that a standard deviation increase in average temperature is associated with a 4.3% increase in net worth and a 12.8% increase in

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[1] Browning and Lusardi (1996) provide an extensive review of early studies on the micro-level determinants of savings behaviour.

[2] Our focus is on savings behaviour and, thus, the outcomes used include indicators of wealth accumulation and differences between wealth over time. Unless otherwise noted, the term savings is used here, and elsewhere in the manuscript, to refer to net worth, wealth or savings rates.

[3] The postcode is a small geographical area in Australia. In urban areas, a postcode broadly corresponds to a town or suburb. In rural or regional areas, postcodes are larger in area terms, but because population density is lower, still have relatively few people. There are approximately 3000 postcodes in Australia; the average area is 2,911 square kilometres with each postcode having an average population of 9,075 people.

savings. When we explore the underpinning mechanisms, we find that time preferences, but not risk preferences, mediate the relationship between temperature shocks and savings.

We also use temperature projections from the most recent climate models from the Coupled Model Intercomparison Project (CMIP6), used in the International Panel on Climate Change (IPCC) sixth assessment report, to simulate how global warming can be expected to affect savings and net worth in the short, medium and long-term. We find that over the course of the rest of the century, if no counter measures are taken to address climate change that net worth would increase by 0.015 standard deviations and savings by 0.043 standard deviations compared with the ‘best case’ scenario for climate change which saw the widespread adoption of renewable energy sources. This result is consistent with temperature shocks making climate change more salient and this causing people to become more future oriented.

We make three main contributions. Our first contribution is to the literature that has examined the relationship between weather and financial outcomes (Krämer & Runde, 1997; Saunders, 1993), which has recently gained additional attention because of climate change. To this point, this literature has primarily focused on the relationship between weather and stock returns (see, e.g., Chang et al., 2008; Hirshleifer & Shumway, 2003; Hou et al., 2019; Krämer & Runde, 1997; Lu & Chou, 2012; Saunders, 1993; Trombley, 1997; Worthington, 2009), and the relationship between temperature shocks, the cost of equity and asset prices (e.g., Balvers et al., 2017; Bansal et al., 2016). We extend this literature to examine how temperature shocks affect household savings, which is important given that household wealth and savings rates are indicators of financial wellbeing (Cobb-Clark et al., 2016). In many countries, asset accumulation and savings remain important components of antipoverty strategies while policies aimed at promoting household financial wellbeing include various incentivised schemes to encourage savings (Beverly & Sherraden, 1999; Borsch-Supan, 2003; Borsch-Supan & Brugiavini, 2001; Borsch-Supan et al., 2001). The importance of savings has also been emphasised in the economic growth literature and has been shown to influence many outcomes linked with growth (Aghion et al., 2016; Cesaratto, 1999; Solow, 1956).

Our second contribution pertains to the channels through which weather influences financial behaviour or decisions. The existing behavioural finance literature linking weather to stock market returns has mostly emphasised investor mood and sentiment as channels through which weather transmits to stock returns (Balvers et al., 2017; Bansal et al., 2016; Hirshleifer & Shumway, 2003). We focus on time and risk preferences as channels through which temperature shocks transmit to savings. Thus, our study also connects with those that examine the relationship between preferences and savings behaviour (Cronqvist & Siegel, 2015; Kimball, 1990; Lusardi, 1998; Skinner, 1988), and the relationship between weather events and preferences (Eckel et al., 2009; Hanaoka et al., 2015; Kahsay & Osberghaus, 2016).

Third, we contribute to the new climate-economy literature. Global temperature variations have been a concern to policymakers. The Intergovernmental Panel on Climate Change (IPCC) estimates that, relative to the period 1986 to 2005, the global mean surface temperature by the end of this century will have increased about 16 times from 0.3 to 4.8 degrees Celsius (IPCC, 2014). With such predicted persistent increases in temperature over the next few decades, understanding the implications of temperature variations is important for assessing and devising policies aimed at addressing the potential economic and social implications of climate change. Yet, in what is perhaps the most extensive review on the new climate-economy literature, Dell et al. (2014, p. 790) find that "despite the broad range of outcomes already studied, there are plausibly important channels that have, to date, received comparatively little study". One such outcome that is yet to be studied is savings. We contribute to the new climate-economy literature by examining the impact of temperature shocks on savings. In doing so, our study relates to those that examine the impact of temperature or climate change on outcomes that influence income, wealth or savings. This literature draws on exogenous temperature shocks to establish causal effects of temperatures on agriculture (Fisher et al., 2012), labour productivity (Cachon et al., 2012; Graff Zivin & Neidell, 2014; Seppanen et al., 2006), income per capita and economic growth (Dell et al., 2009, 2012; Nordhaus, 2006).[4]

Our study also relates to those that examine the relationship between other environmental or weather-related shocks (e.g., rainfall shocks) and savings (Fafchamps et al., 1998; Paxson, 1992; Rosenzweig, 2001). This literature generally focuses on agricultural households in developing countries and how such households use savings and other means to smooth consumption as coping mechanisms to deal with unexpected environmental shocks to income. Although these studies have improved our understanding on how shocks influence savings behaviour in agricultural households, they do not explain how temperature shocks influence savings in a general population sample and the channels through which this occurs.

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[4] See Dell et al. (2014) for a review of the 'new climate-economy' literature.

2. Conceptual Framework

2.1. Temperature shocks, preferences and savings

While standard economic models assume that preferences are stable across time (Stigler & Becker, 1977), a number of more recent studies have found that risk and time preferences can change in response to various shocks, including financial crises, natural disasters and violent conflict. The empirical evidence on the effect of shocks on risk and time preferences is ambiguous. For example, Cameron and Shah (2015), Cassar et al. (2017), Chantarat et al. (2019) and Beine et al. (2020) find that individuals become more risk adverse following a natural shock, while Eckel et al. (2009) and Hanaoka et al. (2015) find that people become more risk loving following a natural shock. Similarly, while Beine et al. (2020), Cassar et al. (2017) and Sawada and Kuroishi (2015) find that people become more impatient following a natural shock, Callen (2015) and Chantarat et al. (2019) find that the opposite is true.

Direct exposure to temperature shocks, in the form of deviations from long-run average temperatures have been shown to increase concern about the effects of climate change (Akerlof et al., 2013; Brooks et al., 2014; Li et al., 2011). Krosnick et al. (2006) provide evidence that those exposed to extreme weather revise upwards their subjective probability of climate change damage occurring. There is also evidence that those exposed to extreme weather events become more pro-environmental. Chantarat et al. (2019) find that those exposed to flooding are less likely to exploit forests or over fish. We expect that the effect of potential future natural disasters, such as those due to climate change, will also have ambiguous effects on current risk and time preferences that will influence savings behaviour.

With respect to the effect of temperature shocks on time preferences, if temperature shocks make climate change more salient, it may make those exposed to temperature shocks more concerned about the future, and less present-oriented; hence, lowering their discount rate. Alternatively, temperature shocks might make people more impatient, leading the discount rate to increase. If people perceive that climate change will cause more disasters in the future and/or lower the future quality of life, this may lower the subjective probability of enjoying future consumption, causing them to save less (Callen, 2015; Cassar et al., 2017).

While there are explicit differences between risk and time preferences, risk and time are linked (Andreoni & Sprenger, 2012), and share several characteristics. On the one hand, weather shocks may engender emotions and behavioural heuristics that make people risk loving (Sagemüller & Mußhoff, 2020). While the psychology of emotional responses to negative shocks is not well-understood, increased salience of catastrophic events may evoke anger – for example anger that the planet is not doing enough to reduce global warming – and anger makes people, particularly men, more risk loving (Hanaoka et al., 2018). However, exposure to weather shocks might make people more risk adverse. The literature on risk assessment suggests that personal experience serves as a readily available heuristic for assessing abstract risks, such as the future risk from climate change. Moreover, people overestimate risks that they personally experience and this is a catalyst for behavioural changes (Whitmarsh, 2008). If direct exposure to extreme events makes people more concerned about climate change, this may lead them to become more risk adverse and save more because of an increase in the perceived likelihood that a disaster will occur in the future or generate a visceral response that results in people having a greater fear of a negative future shock (Cassar et al., 2017).

2.2. Theoretical model

To gain insight into how temperature changes influence savings through time and risk preferences, this section presents a simple lifecycle model with endogenous time and risk preferences. Consistent with the above conjecture, we show that the effect of temperature changes on savings through risk and time preferences is theoretically ambiguous.

Assume that each individual lives for two periods, faces uncertainty in future earnings and derives utility from consumption in current and future periods, c_t and d_{t+1}:

$$U(c_t, d_{t+1}) = \frac{{c_t}^{1-\theta(T)}-1}{1-\theta(T)} + E_t\left\{\beta(T)\left(\frac{{d_{t+1}}^{1-\theta(T)}-1}{1-\theta(T)}\right)\right\}, \tag{1}$$

where T denotes the temperature parameter, $\theta(T) > 0$ is the degree of relative risk aversion and $\beta(T)$ is the discount factor.[5] Note, here, that T is a finite real number and is given by $T = \bar{T} + |x|$, where $\bar{T}$ denotes the average temperature which is fixed and x denotes positive or negative deviations. Hence, a higher T means that temperature is more extreme – either hot or

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[5] $\beta(T) = 1/[1 + \rho(T)]$, where $\rho(T) > 0$ is the rate of time preference or subjective discount rate. We interchangeably use 'a higher discount factor' or 'a lower rate of time preference' or 'a lower discount rate' to refer to 'more patience', and vice versa.

cold - compared with average temperature. The dependence of time and risk preferences on temperature changes, here, is in line with the empirical evidence that temperature changes affect both time and risk preferences (Carias et al., 2021; Wang, 2017).

The budget constraints in the first and second periods are given by

$$c_t = w_t - s_t, \tag{2}$$

$$d_{t+1} = Rs_t + w_{t+1}, \tag{3}$$

where w_t and w_{t+1} are exogenous earnings in the first- and second-periods, respectively, s_t is savings, and R is the exogenous gross interest rate on savings.

Combining (2) and (3) yields the intertemporal budget constraint:

$$c_t = w_t - \frac{d_{t+1} - w_{t+1}}{R} \tag{4}$$

An individual of generation t seeks to maximize the expected utility function in (1) subject to the intertemporal budget constraint (4), which gives the consumption Euler equation:

$$c_t{}^{-\theta(T)} = R\beta(T)E_t\left(d_{t+1}{}^{-\theta(T)}\right) \tag{5}$$

Equation (5) states that an optimal plan requires that the cost in terms of foregone utility of giving up a unit of consumption in period t equals the expected utility gain. Both the utility cost and expected utility gain depend on temperature through time and risk preferences. The utility cost is given by $c_t{}^{-\theta(T)}$ and the expected utility gain is given by the discounted value of the extra expected utility that can be obtained next period through the increase in consumption by R units, $R\beta(T)E_t\left(d_{t+1}{}^{-\theta(T)}\right)$. Using (4) and (5) yields

$$c_t{}^{-\theta(T)} = R\beta(T)E_t\left\{[(w_t - c_t)R + w_{t+1}]^{-\theta(T)}\right\} \tag{6}$$

which implicitly determines the optimal consumption in the current period c_t. Hence, the effect of temperature changes on savings, where $s_t = w_t - c_t$, is *a priori* uncertain and depends on how temperature changes affect consumption through time and risk preferences.

To see this, rewrite (6) as

$$\Upsilon(\cdot) \equiv R\beta(T)E_t\{[(w_t - c_t)R + w_{t+1}]^{-\theta(T)}\} - c_t^{-\theta(T)} = 0 \tag{7}$$

and differentiate (7) with respect to T, which yields [6]

$$\frac{\partial s_t}{\partial T} = -\frac{\partial c_t}{\partial T} = \frac{\frac{\partial \Upsilon(\cdot)}{\partial T}}{\frac{\partial \Upsilon(\cdot)}{\partial c_t}} \tag{8a}$$

where

$$\frac{\partial \Upsilon(\cdot)}{\partial c_t} = \theta(T)\{R^2\beta(T)E_t(d_{t+1}{}^{-\theta(T)-1}) + c_t{}^{-\theta(T)-1}\} > 0 \tag{8b}$$

$$\frac{\partial \Upsilon(\cdot)}{\partial T} = \frac{\partial \beta(T)}{\partial T} RE_t(d_{t+1}{}^{-\theta(T)}) + \frac{\partial \theta(T)}{\partial T}\Omega(\cdot) \tag{8c}$$

$$\Omega(\cdot) \equiv c_t{}^{-\theta(T)} lnc_t - R\beta(T)E_t[(d_{t+1}{}^{-\theta(T)})lnd_{t+1}] \tag{8d}$$

after using $d_{t+1} = (w_t - c_t)R + w_{t+1}$ for substitution. Since the sign for (8c) is ambiguous, the effect of temperatures on savings, $\partial s_t/\partial T$, through time and risk preferences is ambiguous:

$$\frac{\partial s_t}{\partial T} \begin{cases} > 0, & \frac{\partial \beta(T)}{\partial T} RE_t(d_{t+1}{}^{-\theta(T)}) + \frac{\partial \theta(T)}{\partial T}\Omega(\cdot) > 0, \\ = 0, \quad \text{If} & \frac{\partial \beta(T)}{\partial T} RE_t(d_{t+1}{}^{-\theta(T)}) + \frac{\partial \theta(T)}{\partial T}\Omega(\cdot) = 0, \\ < 0, & \frac{\partial \beta(T)}{\partial T} RE_t(d_{t+1}{}^{-\theta(T)}) + \frac{\partial \theta(T)}{\partial T}\Omega(\cdot) < 0 \end{cases}$$

Therefore, under certain conditions, extreme temperature changes can either increase savings or decrease savings. We summarize these conditions in the following propositions.

Proposition 1. *Suppose the effect of temperatures on time preference, $\partial\beta(T)/\partial T$, dominates that on risk preference, $\partial\theta(T)/\partial T$, so the sign of $\partial s_t/\partial T$ follows that of $\partial\beta(T)/\partial T$. Then,*

(i) $\partial s_t/\partial T > 0$ *if* $\partial\beta(T)/\partial T > 0$;

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[6] We assume that temperature changes do not affect earnings *w* and the gross interest rate *R*.

(ii) $\partial s_t/\partial T < 0$ *if* $\partial\beta(T)/\partial T < 0$.

Proposition 1 suggests that when time preferences respond more than risk preferences to changes in temperature, extreme temperature changes, i.e., higher T, can either increase or decrease savings, depending on whether higher T make people more, or less, impatient. If higher T lead to more patience, $\partial\beta(T)/\partial T > 0$, then savings increase, $\partial s_t/\partial T > 0$, and vice versa. The intuition is that if extreme temperature change leads to more patience, the discount rate decreases which implies that people are more future oriented and more willing to forgo present consumption for future consumption; hence, savings increase, $\partial s_t/\partial T > 0$. On the other hand, if extreme temperature changes lead to more impatience, $\partial\beta(T)/\partial T < 0$, the discount rate increases which implies that people are less future oriented and more likely to substitute present for future consumption; hence, savings decrease, $\partial s_t/\partial T < 0$.

Proposition 2. *Suppose the effect of temperatures on risk preference,* $\partial\theta(T)/\partial T$, *dominates that on time preference,* $\partial\beta(T)/\partial T$, *so the sign of* $\partial s_t/\partial T$ *follows that of* $\partial\theta(T)/\partial T$. *Then,*

(i) $\partial s_t/\partial T > 0$*: if* $\partial\theta(T)/\partial T > 0$ *and* $\Omega(\cdot) > 0$, *or alternatively, if* $\partial\theta(T)/\partial T < 0$ *and* $\Omega(\cdot) < 0$*;*

(ii) $\partial s_t/\partial T < 0$*: if* $\partial\theta(T)/\partial T > 0$ *and* $\Omega(\cdot) < 0$, *or alternatively, if* $\partial\theta(T)/\partial T < 0$ *and* $\Omega(\cdot) > 0$.

Proposition 2(i) suggests that when risk preferences respond more than time preferences to changes in temperature, extreme temperature changes, i.e., higher T, generate a positive savings effect, $\partial s_t/\partial T > 0$, if either of the following two conditions hold. First, higher T lead to a higher degree of risk aversion, $\partial\theta(T)/\partial T > 0$, and the returns to savings adjusted by the discount factor $R\beta$ are sufficiently low such that $\Omega(\cdot) > 0$.[7] Second, higher T lead to a lower degree of risk aversion, $\partial\theta(T)/\partial T < 0$, and the returns to savings adjusted by the discount factor $R\beta$ are sufficiently high, such that $\Omega(\cdot) < 0$. The intuition underpinning this result is implied by the consumption Euler equation (5). Lower $R\beta$ causes future consumption and savings to fall, but if θ is high, this would result in a sharp rise in the marginal utility of future consumption, such that not much would be lost by increasing future consumption. Alternatively, higher $R\beta$ causes future consumption to rise, this outcome will be optimal if θ

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[7] We assume that $lnc_t > 0$ and $lnd_{t+1} > 0$.

is low, in order to avoid a sharp decline in the marginal utility of future consumption. Similar intuition applies to Proposition 2(ii).

Using results in Propositions 1 and 2, we obtain Corollary 1:

Corollary 1. $\partial s_t/\partial T > 0$ *if* $\partial\beta(T)/\partial T > 0$, $\partial\theta(T)/\partial T > 0$ *and* $\Omega(\cdot) > 0$, *or alternatively, if* $\partial\beta(T)/\partial T > 0$, $\partial\theta(T)/\partial T < 0$ *and* $\Omega(\cdot) < 0$. *On the other hand,* $\partial s_t/\partial T < 0$ *if* $\partial\beta(T)/\partial T < 0$, $\partial\theta(T)/\partial T > 0$ *and* $\Omega(\cdot) < 0$, *or alternatively, if* $\partial\beta(T)/\partial T < 0$, $\partial\theta(T)/\partial T < 0$ *and* $\Omega(\cdot) > 0$.

The intuition behind Corollary 1 follows that of Propositions 1 and 2. For example, if higher temperatures cause people to be more patient $\partial\beta(T)/\partial T > 0$, more risk averse $\partial\theta(T)/\partial T > 0$ and the returns to savings adjusted by the discount factor $R\beta$ are sufficiently low, such that $\Omega(\cdot) > 0$, then higher temperatures will lead to higher savings.

3. Data and Variables

We use data from two main sources. Our first source is household- and individual-level data available in HILDA. Described in more detail in Watson and Wooden (2012), the HILDA Survey is a household longitudinal survey that focuses on work, health, income and the socioeconomic aspects of the lives of Australians. The survey, which is nationally representative, commenced in 2001 and has produced 18 annual waves. Our analysis is restricted to waves 2, 6, 10, 14 and 18 given that information on household net worth and savings are collected only in these waves. We restrict our analysis to households in which the reference person is aged between 25 and 75 years.[8] We use the restricted release of HILDA, that provides information on the postcode in which respondents live. This allows us to merge data from HILDA with ERA5 satellite reanalysis data taken from the ECMWF. ERA5 combines information from ground stations, satellites, weather balloons and other inputs with a climate model to provides hourly estimates of several climate-related variables at a grid spacing of around 31 km globally with data available since 1979 (Dell et al., 2014). We use air temperature measured as annual averages and map the grid spacings in ERA5 to postcodes.

3.1. Temperature shocks

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[8] HILDA does not identify a household head or reference person. Consistent with previous studies, we define the household reference person as the individual within each household who has the highest income (see, e.g., Awaworyi Churchill & Smyth, 2020).

Consistent with the literature, we define temperature shocks at time t for each postcode (p) as the difference between observed temperature at t and the long-run average for each postcode p, divided by the long-run standard deviation for the postcode (see, e.g., Graff Zivin et al., 2020; Hirvonen, 2016; Letta et al., 2018). Hence, our measure of temperature shock or anomaly represents the deviation in actual temperature from the historical mean for postcode p in time t, standardised by the standard deviation. In robustness checks, we also use alternative indicators of temperature including actual (unstandardised) temperature deviation, defined as the difference between observed temperature and the long-run average; measures of "hot weather", defined as temperature deviation greater than one standard deviation; and "cold weather", defined as temperature deviation less than one standard deviation.

3.2. Savings and net worth

The measure of wealth or household savings in HILDA is household total net worth derived from detailed information on household assets and liabilities (Cobb-Clark et al., 2016; Heady, 2003). Household total net worth is defined as the sum of net financial and non-financial wealth. Net financial wealth in HILDA is defined as "the sum of total interest earning assets in banks and other institutions, total stocks and mutual funds, and total other investments (life insurance, trust funds, and collectibles), minus the total value of unsecured debt (including car loans)" (Cobb-Clark et al., 2016, p. 115). Non-financial wealth is captured by four broad asset categories, including vehicles, business equity, real estate wealth and pensions. Vehicle wealth is the total value of all vehicles owned by households including cars, trucks, caravans and boats, among others, while business equity is the net value of all household business assets. Real estate wealth captures equity in the household's primary residence, holiday homes and other properties owned. Wealth from pensions is the current value of the household's pension entitlements including employee and employer contributions to superannuation.[9] We consider total net worth, as well as financial and non-financial assets separately. We also consider the four individual components of non-financial assets in alternating models.[10]

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[9] Pension wealth in Australia is generated through savings that has voluntary and compulsory components. The compulsory component is through the superannuation guarantee, which commenced in 1992 and requires compulsory contributions of at least 9.5% of employee's salaries and wages from employers into superannuation funds. Employees are also allowed to make voluntary contribution into their superannuation funds, while some employees also receive government co-contributions. Cobb-Clark et al. (2016) provide more details on the nature of pensions in Australia.

[10] All monetary values are adjusted for inflation.

We determine savings as the difference in household wealth over time. Given information on household wealth is reported in four-yearly intervals in waves 2, 6, 10, 14 and 18, our measure of savings is the difference in household wealth between each consecutive wave.

3.3. Time and risk preferences

To examine if time and risk preferences are mechanisms through which temperature shocks influence household savings, we use measures of risk and time preferences in HILDA. Questions on financial planning horizon are commonly used in the literature as a proxy for time preference (see, e.g.,Brown & Van der Pol, 2015; Khwaja et al., 2006; Picone et al., 2004; Samwick, 1998). Time preference in HILDA is based on the survey question: "In planning your savings and spending which of the following time periods is most important to you?" The response to this question is coded on a six-point scale as follows: "1 is next week; 2 is next few months; 3 is next year; 4 is next two to four years; 5 is next five to ten years; and 6 is more than ten years ahead". Individuals with longer planning horizons are taken to have lower time preference rates than their counterparts with shorter planning horizons (Brown & Van der Pol, 2015). Our measure of time preference is an ordinal scale capturing the six choices, such that one represents the shortest planning horizon and, thus, the highest possible time preference and six represents the longest planning horizon and, thus, the lowest possible time preference.

Our proxy for risk preferences is based on the Survey of Consumer Finances (SCF) risk assessment measure (Brown & Van der Pol, 2015; Grable & Lytton, 1999; Hanna & Lindamood, 2004). The survey question in HILDA asks respondents: "Which of the following statements comes closest to describing the amount of financial risk that you are willing to take with your spare cash? That is, cash used for savings or investment". The response to this question is coded on a four-point scale as follows: "1 represents I take substantial financial risk expecting to earn substantial returns; 2 represents I take above average financial risks expecting to earn above average returns; 3 represents I take average financial risks expecting to earn average returns; and 4 represents I am not willing to take any financial risks".[11] The stability of this measure as an indicator of risk preference has been confirmed in multiple contexts (Grable & Lytton, 2001). We code responses on risk preferences on an ordinal scale reflecting

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[11] For respondents without any spare cash, they are asked to assume they "had some spare cash that could be used for savings or investment" and responses are coded on the same scale.

the four possible choices, such that one represents the highest risk preference (risk-loving) and four represents the lowest risk preference (risk-averse). Table A1 in the appendix presents a description and summary statistics of all variables employed in the analysis.

4. Empirical Strategy

We estimate the following empirical specification:

$$S_{it} = \gamma_0 + \gamma_1 T_{st-1} + \gamma_2 R_{st-1} + \mu_r + \delta_t + \varepsilon_{it} \qquad (9)$$

where S_{it} is the savings of household i living in postcode p in year t. We use two measures of savings; namely, total net worth and savings rate. T_{st-1} is the temperature shock for postcode p in the previous period $(t-1)$. We consider temperature shocks in the previous period as our explanatory variable given that it takes time for wealth to be accumulated and, thus, the effects of temperature shocks on savings and net worth may not be contemporaneous. This is also in line with the existing literature examining the impact of temperature shocks on other outcomes (Hirvonen, 2016). Dell et al. (2014) recommend controlling for other weather variables. We control for rainfall, denoted by R_{st-1}. Finally, state fixed effects (μ_r) and time fixed effects (δ_t) are also included to absorb the effects of unobservable time-invariant state or time characteristics, and ε_{it} denotes the error term. We follow the literature and estimate equation (1) using a fixed effect approach that controls for household, location and year fixed effects with standard errors clustered at the postcode level (see, e.g., Burke et al., 2011; Dell et al., 2012; Deschênes & Greenstone, 2007; Fisher et al., 2012; Hirvonen, 2016). By controlling for household and year fixed effects, the impact of temperature shocks is identified from location-specific deviations in temperature, while controlling for annual shocks common to all postcodes. In various sensitivty checks, we also control for a wider range of fixed effects including location-by-year fixed effects and time trends among others.

Dell et al. (2014) stress that it is important to not "over control" by including covariates that might be influenced by temperature shocks. Our main results, therefore, do not include household characteristics, which in various have studies have been show to be correlated with temperature shocks. However, in robustness checks, for completeness we include demographic controls and our main conclusions remain qualitatively unchanged.

5. Results

5.1. Main results

Table 1 presents results for the effects of temperature shocks on household net worth and savings. Columns 1 and 2 report results for net worth, while Columns 3 and 4 report results for savings. In Columns 1 and 3, we start with a baseline OLS model that does not control for household fixed effects, while in Columns 2 and 4, we present results from a panel fixed effect model that controls for relevant fixed effects. Across all columns of Table 1, we find that the coefficients on temperature shocks are positive, suggesting temperature shocks are positively associated with household net worth and savings. When temperature deviations are larger than the historical mean, households save more and accumulate more wealth. Specifically, a standard deviation increase in average temperature in the previous period is associated with a 4.9% increase in net worth in Column 1; however, the magnitude of the coefficient on temperature shock marginally declines in Column 2 once we control for household fixed effects. Here, a standard deviation increase in average temperature is associated with a 4.3% increase in net worth. The results presented in appendix Table A2 for the non-log transformation of net worth show that the 4.3% increase in net worth corresponds with a $32,625 increase in net worth. In Columns 3 and 4, we find that a standard deviation increase in average temperature is associated with a 13.3% and 12.8% increase in savings, respectively.

The results in Table 1 for net worth do not capture differences in assets. In Table 2, we examine heterogeneity across components of net worth. Components of non-financial assets, such as vehicles, may depreciate or be destroyed more quickly by severe temperature shocks compared to financial assets (De la Fuente, 2007). Column 1 of Table 2 reports the results for financial assets; Column 2 reports results for business equity; Column 3 reports results for real estate; while Columns 4 and 5 report results for vehicles and pensions, respectively. The results are only significant for real estate wealth and vehicles. In Columns 3 and 4, a standard deviation increase in average temperature is associated with a 5.6% increase in real estate wealth and a 2.9% increase in vehicles, respectively. These results suggest that the effects of temperature shocks are mostly driven by effects on real estate wealth and vehicles.

The finding for real estate wealth reflects that purchasing real estate is a popular form of investment in Australia. Most Australians who seek to invest typically invest in real estate, with one in five Australians owning an investment property (ATO, 2018). Reasons for this are negative gearing tax provisions, coupled with low interest rates, and a general perception that home ownership and real estate investments are one of the safest ways of accumulating wealth (Colic-Peisker & Johnson, 2010; Melser & Hill, 2019). The reliance of Australian households on private vehicles is a likely explanation for the effect on vehicles. Reflecting Australia's large landmass and urban sprawl, 82 per cent of Australian households own at least one private vehicle (ABS, 2021), which means that Australia has one of the highest rates of private vehicle ownership in the world. Many people live in the outer suburbs of large cities, such as Melbourne and Sydney, and commute long distances for work. These suburbs are generally not well served by public transport, meaning that many people have no option but to own a car (Awaworyi Churchill & Smyth, 2019; Fritze, 2007; Rosier & McDonald, 2011).

5.2. Robustness checks

In this section, we examine the robustness of our results to a number of checks. In Table 3, we examine the robustness of our results to alternative measures of temperature shocks. Our main results in Table 1 are based on temperature shocks measured as the deviation of actual temperature from the historical mean standardised by the standard deviation. In Panel A of Table 3, we examine the robustness of our results to an alternative measure of temperature shock defined as the actual (unstandardised) temperature deviation, which we calculate as the difference between observed temperature and the long-run average. In Panels B and C of Table 3, we define temperature shocks in terms of extreme heat (greater than one standard deviation above the mean) and extreme cold (less than negative one standard deviation below the mean).

Our results are robust to the alternative measure of temperature shocks in Panel A. In Panel B we find that extreme hot temperature is associated with an increase in net worth and savings, while the effect of extreme cold temperature is statistically insignificant. Given its climate, Australia tends to experience many more hotter days than colder days and, thus, in our main results temperature shocks mostly reflect extreme hot temperatures as opposed to cold temperatures. Specifically, from our data we observe that extreme hot temperatures represent the bulk of temperature shocks and that they are, on average, 4% higher than the historical mean. The finding that hotter temperatures is associated with higher net worth and savings is consistent with findings in the literature that show sunny days and warmer temperatures are associated with better stock market performance, while colder temperatures are associated with poorer performance (Hirshleifer & Shumway, 2003; Hou et al., 2019).

Our main results examine the impact of temperature shocks in t-1 on savings and net worth in period t. In further checks, we consider the preceding two and three periods. Thus, in Panels A and B of Table 4, we use an indicator of temperature shock that reflects temperature in the two and three years before the savings information was collected, respectively. Given that information on net worth is captured every four years in HILDA, in Panel C, we use temperature deviations over the four years between net worth measurements to examine the impacts of temperature shocks. We find that our results remain robust.

In our main results, we do not control for the characteristics of the respondent, which are potentially endogenous, to avoid over controlling (Dell et al., 2014). However, as a check we control for characteristics of the household reference person. Our controls for characteristics of the household reference person include age, employment status, marital status, number of dependants, education, and health status (see Table A1 for full list). Table A2 presents the results with these controls. We find that the results are very similar to those in Table 1. Specifically, a standard deviation increase in average temperature in the previous period is associated with a 4.3% increase in net worth and a 12.7% increase in savings.

Next, we examine the robustness of our results to an alternative dataset. Our main analysis is based on satellite re-analysis data taken from ECMWF. To examine the robustness of our results, we use alternative satellite data from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis. This data set is derived from a global spectral model with a resolution of 2.5° latitude by 2.5° longitude. Previous studies have shown that the ERA5 and NCEP produce consistent estimates in terms of predicting temperature and precipitation (Auffhammer et al., 2013). The results using the alternative datasets, reported in appendix Table A4, show that our results are robust.

In Table A5, we examine if the impact of temperature shocks has heterogenous effects across postcodes that are ‘warm’ and ‘cold’. Following Awaworyi Churchill et al. (2020), we consider postcodes with actual temperatures above and below the mean as ‘warm’ and ‘cold’, respectively. The sub-sample analysis results presented in appendix Table A5 show that the effects of temperature shocks on net worth and savings for ‘warm’ postcodes are consistent with our main results. This is consistent with the findings in Table 3, which show that the positive effect of temperature shocks is driven by extreme hot temperature.

In another check, we examine the robustness of our results to the inclusion of a rich set of location and time fixed effects including district fixed effects, local government area (LGA) fixed effects, linear time trend fixed effects, month of interview fixed effects and multiple interactions between location and time fixed effects. The results for each of these exercises, reported in Table A6, suggest that the effects of temperature shocks on net worth and savings are consistently robust to the control of different fixed effects.

In a final check, we examine the impact of temperature shocks across different wealth distributions. To do this, we estimate quantile regressions of savings. These regressions capture the savings gaps associated with temperature shocks at different points of the wealth distribution. We consider the 25th, 50th and 75th quantiles, and thus, the results represent the marginal effects associated with each quantile of the savings distribution. For completeness, we also report OLS estimates, which represent the marginal effect at the mean. The quantile regression results reported in Table A7 are consistent with our main results.

5.3. Time and risk preferences as mediators

In this section, we perform a mediation analysis following the approach in Alesina and Zhuravskaya (2011) to empirically examine the role of risk and time preferences as channels of the relationship between temperature shocks and savings. With this approach, for risk preferences or time preferences to qualify as mediators, in addition to being correlated with temperature shocks, they should also be correlated with savings and the inclusion of risk or time preferences as an additional covariate in the regression linking temperature shocks to savings should either decrease the magnitude of the coefficient on temperature shocks (i.e., partial mediation) or render it statistically insignificant (full mediation).

We report the results for the effects of temperature shocks on risk preferences and time preferences in alternating models in Panel A of Table 5. The deviation of temperature from the mean could result in an increase in temperature (hot shocks) or decrease in temperature (cold shocks). The results in Table 3 suggest that, consistent with Australia’s hot climate, the positive effect of temperature shocks on savings is driven by hot shocks. In Panels B and C, we report the results for the effects of hot and cold temperature shocks, respectively, separately on risk preference and time preference. In each case, the relationship between temperature shocks and risk preferences are insignificant. In Panel A, the relationship between temperature shocks and time preferences are positive, implying that an increase in the deviation of temperature from the historical mean makes people more patient and future oriented. In Panels B and C, we find heterogeneous effects; that is hot temperature shocks make people more patient and future oriented, while cold temperature shocks make people more impatient.

Given the statistically significant effect of temperature shocks on time preference, in Panel A of Table 6, we include time preference as an additional covariate in alternating models for net worth and savings. In Columns 1 and 3, we report the baseline effect of temperature shocks on net worth and savings without time preference for comparison, while in Columns 2 and 4, we include time preference as an additional covariate. We find that being more future oriented is associated with an increase in savings and the inclusion of time preference as an additional covariate reduces the magnitude of the coefficient on temperature shocks, suggesting partial mediation. Specifically, for net worth, the effect of temperature shocks in the baseline model is 0.043 however, with the inclusion of time preference as a covariate, this drops to 0.032. Thus, the observed direct effect of temperature shocks on net worth is 0.032 while the indirect effect channelled through time preference is 0.011, which represents a sizeable 34.4% of the direct effect. Similarly, for savings, the effect of temperature shocks reduces from 0.128 to 0.116 with the inclusion of time preference as an additional covariate. Thus, the direct effect of temperature shocks on savings is 0.116 while the indirect effect channelled through time preference is 0.012, which represents 10.3% of the direct effect.

In Panel B of Table 6, we examine if time preferences mediate the relationship between hot temperature shocks and savings. [12] Our results are consistent with those in Panel A. For net worth, the effect of hot temperature shocks in the baseline model is 0.090; however, with the inclusion of time preference as a covariate, this drops to 0.057, while for savings, the effect of temperature shocks reduces from 0.140 to 0.103 and becomes statistically insignificant with the inclusion of time preference as an additional covariate.

These results viewed together suggest that while risk preference is not a mediator, time preference is a mechanism through which temperature shocks transmit to savings, and that the findings are driven by the effects of hot temperature shocks. Thus, by making people more future oriented, (hot) temperature shocks increase net worth and savings. These findings are consistent with our theoretical predictions in Proposition 1.1.

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[12] We do not consider cold temperature shocks here given that in Table 3 we found that cold shocks have no direct effect on savings and, thus, a mediating effect is not possible in this case.

5.4.Climate change, net worth and savings

We simulate changes in future net worth and savings due to climate change. To do this, we combine the estimate from Columns 2 and 4 of Table 1 with data on simulated weather conditions at the postcode level for 2021 to 2099. Future climate change data are sourced from the NASA Earth Exchange (NEX) Global Daily Downscaled Projections (GDDP) and the CMIP6 Project. The NEX-GDDP-CMIP6 data provides average temperature projections for the short term (2021 to 2040), the medium term (2041–2060) and the long term (2061–2099) using nine global climate models (GCMs).[13] We focus on RCP4.5 and RCP8.5, which are two extreme emission pathways that represent opposite ends of the spectrum depending on the uptake of renewable energy.[14] Given that estimates of the economic effects of climate change are sensitive to the specific choice of GCM (Burke et al., 2015), we use future projections from eight of the nine GCMs at 2.5-minutes spatial resolution to ensure our results are robust.[15]

We follow Burke et al. (2009) in generating monthly mean temperature projections using three steps. First, we use daily average temperature over the period 2001 to 2020 to construct monthly average temperature and probability distribution functions. Second, we calculate projected changes in monthly average temperatures as the difference between the projected monthly average temperatures and the historical average temperatures. Third, we assume the distribution of the projected daily average temperature closely mirrors that of historical temperature, and, thus, construct the distribution of average temperature in the short, medium and long terms for the RCP4.5 and RCP8.5 emission pathways.

Table 7 summarizes the projected changes for temperature and wealth for each of the eight GCMs for the RCP4.5 and RCP8.5 emission pathways in the short, medium and long terms, while Table 8 summarizes the projected changes for temperature on savings. Under the RCP4.5 pathway, the average change in temperature peaks at 1.448 standard deviations in the long-term. Under the RCP8.5 pathway, in which current trends are not curbed with

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[13] The nine GCMs are BCC-CSM2-MR, CNRM-CM6-1, CNRM-ESM2-1, CanESM5, GFDL-ESM4, IPSL-CM6A-LR, MIROC-ES2L, MIROC6, MRI-ESM2-0. Details are available at: https://www.worldclim.org/data/cmip6/cmip6climate.html

[14] RCP denotes Representative Concentration Pathway, which captures future trends in climate change under alternative scenarios of human activities. RCP8.5 tracks emissions consistent with current trends (business as usual scenario in which greenhouse gas emissions go unchecked), while RCP4.5 considers a scenario with increased reliance on renewable energy and less reliance on coal-fired power.

[15] GFDL-ESM4 is excluded because future projections are not available for this under the RCP8.5 pathway.

countervailing measures, such as renewable energy replacing coal, the average change in temperature peaks at 1.807 standard deviations in the long term.

In Table 7, using the maximum temperature projection across CGMs for the RCP4.5 pathway, average temperature increases are associated with at most a 0.055, 0.059 and 0.063 standard deviation increase in net worth in the short, medium and long terms, respectively. For the RCP8.5 pathway, average temperature increases are associated with at most a 0.057, 0.063 and 0.078 standard deviation increase in net worth in the short, medium and long terms, respectively. Thus, without any countervailing strategies to address climate change between 2021 and 2099, there would be an additional 0.015 standard deviation increase in net worth as a result of climate change, compared with the 'best case' RCP4.5 scenario.[16]

In Table 8, for the RCP4.5 pathway, average temperature increases are associated with at most a 0.165, 0.174 and 0.188 standard deviation increase in the savings in the short, medium and long terms, respectively. For the RCP8.5 pathway, average temperature increases are associated with at most a 0.169, 0.192 and 0.231 standard deviation increase in savings in the short, medium and long terms, respectively. Thus, without any countervailing strategies to address climate change, there would be an additional 0.043 standard deviation increase in savings as a result of climate change compared with the 'best case' RCP4.5 scenario.

6. Conclusion

We developed a simple model that explains how extreme temperature change influences household savings and wealth via risk and time preferences. We then used longitudinal household data from the HILDA survey and temperature data to examine the direct and indirect effect of temperature shocks on savings and wealth. We find that temperature shocks are associated with higher net worth and saving. We also find that temperature shocks influence household savings and net worth via effects on time preferences, but not risk preferences. The results are driven by hot temperature shocks, while cold temperature shocks are insignificant.

Employing data on future temperature projections for the rest of the century, we find that climate change will generate an increase in savings and net worth compared with the best-case

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[16] Under RCP4.5, in which the government actively promotes renewables, we can expect at most a 0.063 standard deviation increase in net worth and under RCP8.5, in which the government does nothing, we can expect at most a 0.078 standard deviation increase in net worth. The difference in outcomes under the two pathways is a 0.015 (i.e., 0.078-0.063) standard deviation increase in net worth.

scenario in which there is widespread adoption of renewables. One way to interpret this finding is that experiencing extreme heat makes the potential consequences of climate change more salient. This causes them to become more concerned about the future and, hence, to save more.

A limitation of our findings is that we do not have data on respondents' attitudes to climate change. We make inferences about how their attitudes to climate changes are influenced by extreme changes in the weather from their inferred risk and time preferences. It would be interesting to see if respondents' attitudes to climate change mediated the relationship between temperature shocks and savings. One avenue for future research might be to explore whether attitudes to climate change are a channel linking temperature to savings using datasets that contain information on attitudes to climate change and savings, matched with weather data.

Our results suggest that temperature shocks could affect many fundamental economic outcomes for which savings are a channel. Future studies could examine the mediating role of savings in the relationship between temperature shocks and growth, given the role of savings in economic growth. Given the importance of savings as a fundamental variable in economic growth, it is possible that temperature shocks via savings indirectly affect several economic outcomes. That temperature shock promotes net worth could be a location specific effect, especially given Australia's unique climate. Future studies could examine this relationship in other contexts, particularly in colder climates where cold weather shocks are likely to be dominant, to determine if the dynamics vary in different climatic contexts.

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Table 1: Impact of temperature shocks on savings (main results)

Dependent variable	Net worth		Savings	
	OLS (1)	Panel (2)	OLS (3)	Panel (4)
Temperature shock	0.049**	0.043***	0.133***	0.128***
	(0.021)	(0.015)	(0.038)	(0.049)
Observations	25,732	25,732	7,078	7,078
Controlling for rainfall	Yes	Yes	Yes	Yes
Postcode FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Notes: Robust standard errors in parentheses; standard errors are clustered at postcode level; *** p<0.01, ** p<0.05, * p<0.1

Table 2: Components of net worth

Dependent variable	Financial assets	Business equity	Real estate	Vehicles	Pensions
	(1)	(2)	(3)	(4)	(5)
Temperature shock	-0.011	0.009	0.056***	0.029**	-0.020
	(0.021)	(0.051)	(0.010)	(0.014)	(0.016)
Observations	25,732	25,732	18,766	23,808	21,829
Controlling for rainfall	Yes	Yes	Yes	Yes	Yes
Postcode FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors in parentheses; standard errors are clustered at postcode level; *** p<0.01, ** p<0.05, * p<0.1

Table 3: Alternative measures of shocks

Dependent variable	Net worth	Savings
	(1)	(2)
Panel A: Temperature deviation from the mean		
Temperature deviation	0.113***	0.318***
	(0.039)	(0.116)
Observations	25,732	7,078
Panel B: Extreme hot temperature (> 1sd)		
Hot temperature	0.090***	0.140**
	(0.026)	(0.063)
Observations	25,732	7,078
Panel C: Extreme cold temperature (< -1sd)		
Cold temperature	-0.113	-0.175
	(0.077)	(0.207)
Observations	25,732	7,078
Controlling for rainfall	Yes	Yes
Postcode FE	Yes	Yes
Time FE	Yes	Yes

Notes: Robust standard errors in parentheses; standard errors are clustered at postcode level; *** p<0.01, ** p<0.05, * p<0.1

Table 4: Lag of temperature shocks

Dependent variable	Net worth	Saving
	(1)	(2)
Panel A: Shock in t-2		
Temperature shock	0.039***	0.057**
	(0.008)	(0.026)
Observations	20,482	7,078
Panel B: Shock in t-3		
Temperature shock	0.037**	0.076*
	(0.017)	(0.044)
Observations	20,482	7,078
Panel C: Shock over four years		
Temperature shock	0.064***	0.088*
	(0.015)	(0.049)
Observations	25,732	7,078
Controlling for rainfall	Yes	Yes
Postcode FE	Yes	Yes
Time FE	Yes	Yes

Notes: Robust standard errors in parentheses; standard errors are clustered at postcode level; *** p<0.01, ** p<0.05, * p<0.1

Table 5: Impact of temperature shocks on mediators

	(1)	(2)
Dependent variable	Risk preference	Time preference
Panel A: Temperature shocks		
Temperature shock	0.003	0.044***
	(0.003)	(0.007)
Controlling for rainfall	Yes	Yes
Observations	25,732	25,732
Panel B: Extreme hot temperature (> 1sd)		
Hot temperature	0.011	0.107***
	(0.013)	(0.017)
Controlling for rainfall	Yes	Yes
Observations	25,732	25,732
Panel C: Extreme cold temperature (< -1sd)		
Cold temperature	-0.013	-0.226***
	(0.009)	(0.033)
Controlling for rainfall	Yes	Yes
Observations	25,732	25,732

Notes: Robust standard errors in parentheses; standard errors are clustered at postcode level *** p<0.01, ** p<0.05, * p<0.1

Table 6: Impact of mediators on savings

	(1)	(2)	(3)	(4)
Dependent variable	Net worth	Net worth	Savings	Savings
Panel A: Temperature shocks				
Temperature shock	0.043***	0.032***	0.128***	0.116***
	(0.015)	(0.012)	(0.049)	(0.038)
Time preference		0.044***		0.036*
		(0.006)		(0.020)
Controlling for rainfall	Yes	Yes	Yes	Yes
Observations	25,732	25,732	7,078	7,078
Panel B: Extreme hot temperature (> 1sd)				
Hot temperature	0.090***	0.057**	0.140**	0.103
	(0.026)	(0.022)	(0.063)	(0.064)
Time preference		0.044***		0.035*
		(0.006)		(0.020)
Controlling for rainfall	Yes	Yes	Yes	Yes
Observations	25,732	25,732	7,078	7,078

Notes: Robust standard errors in parentheses; standard errors are clustered at postcode level; *** p<0.01, ** p<0.05, * p<0.1

Table 7: Simulated effect of temperature on net worth 2021-2099

	Representative Concentration Pathway (RCP) 4.5					
	Short-term (2021-2040)		Medium-term (2041-2060)		Long-term (2061-2099)	
GCM Models	ΔTemperature	ΔWealth	ΔTemperature	Δ Wealth	ΔTemperature	Δ Wealth
BNU_ESM	1.246	0.054	1.297	0.056	1.400	0.060
CCSM4	1.266	0.054	1.314	0.057	1.384	0.060
CNRM_CM5	1.180	0.051	1.245	0.054	1.326	0.057
CanESM2	1.261	0.054	1.356	0.058	1.448	0.062
IPSL_CM5A_MR	1.279	0.055	1.361	0.059	1.472	0.063
MIROC_ESM	1.286	0.055	1.313	0.056	1.441	0.062
MIROC_ESM_CHEM	1.257	0.054	1.327	0.057	1.447	0.062
MRI_CGCM3	1.142	0.049	1.181	0.051	1.269	0.055
	Representative Concentration Pathway (RCP) 8.5					
	Short-term (2021-2040)		Medium-term (2041-2060)		Long-term (2061-2099)	
GCM Models	ΔTemperature	Δ Wealth	ΔTemperature	Δ Wealth	ΔTemperature	Δ Wealth
BNU_ESM	1.246	0.054	1.297	0.056	1.400	0.060
CCSM4	1.264	0.054	1.396	0.060	1.620	0.070
CNRM_CM5	1.189	0.051	1.352	0.058	1.554	0.067
CanESM2	1.318	0.057	1.503	0.065	1.793	0.077
IPSL_CM5A_MR	1.296	0.056	1.454	0.063	1.807	0.078
MIROC_ESM	1.260	0.054	1.346	0.058	1.643	0.071
MIROC_ESM_CHEM	1.233	0.053	1.351	0.058	1.668	0.072
MRI_CGCM3	1.161	0.050	1.275	0.055	1.489	0.064

Notes: Change in temperature and net worth is measured in standard deviation. Data on simulated weather conditions at the postcode level are from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP). The projection is estimated using the coefficient on the net wealth of 0.043 reported in Column (2) of Table 1.

Table 8: Simulated effect of temperature on saving 2021-2099

	Representative Concentration Pathway (RCP) 4.5					
	Short-term (2021-2040)		Medium-term (2041-2060)		Long-term (2061-2099)	
GCM Models	∆Temperature	∆Saving	∆Temperature	∆ Saving	∆Temperature	∆ Saving
BNU_ESM	1.246	0.159	1.297	0.166	1.400	0.179
CCSM4	1.266	0.162	1.314	0.168	1.384	0.177
CNRM_CM5	1.180	0.151	1.245	0.159	1.326	0.170
CanESM2	1.261	0.161	1.356	0.174	1.448	0.185
IPSL_CM5A_MR	1.279	0.164	1.361	0.174	1.472	0.188
MIROC_ESM	1.286	0.165	1.313	0.168	1.441	0.184
MIROC_ESM_CHEM	1.257	0.161	1.327	0.170	1.447	0.185
MRI_CGCM3	1.142	0.146	1.181	0.151	1.269	0.162
	Representative Concentration Pathway (RCP) 8.5					
	Short-term (2021-2040)		Medium-term (2041-2060)		Long-term (2061-2099)	
GCM Models	∆Temperature	∆ Saving	∆Temperature	∆ Saving	∆Temperature	∆ Saving
BNU_ESM	1.246	0.159	1.297	0.166	1.400	0.179
CCSM4	1.264	0.162	1.396	0.179	1.620	0.207
CNRM_CM5	1.189	0.152	1.352	0.173	1.554	0.199
CanESM2	1.318	0.169	1.503	0.192	1.793	0.230
IPSL_CM5A_MR	1.296	0.166	1.454	0.186	1.807	0.231
MIROC_ESM	1.260	0.161	1.346	0.172	1.643	0.210
MIROC_ESM_CHEM	1.233	0.158	1.351	0.173	1.668	0.214
MRI_CGCM3	1.161	0.149	1.275	0.163	1.489	0.191

Notes: Change in temperature and savings is measured in standard deviation. Data on simulated weather conditions at the postcode level are from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP). The projection is estimated using the coefficient on the saving of 0.128 reported in Column (4) of Table 1.

Appendix

Table A1: Variable descriptions and summary statistics

Variables	Description	Mean	St. Dev
Saving behaviors			
Net worth	Total net worth (in log)	12.505	1.888
Saving	Change in net worth between two periods over permanent income (in log)	-0.749	1.522
Financial assets	Value of financial assets (in log)	11.089	2.449
Equity	Value of equity assets (in log)	3.419	4.803
Property	Value of property assets (in log)	13.086	0.848
Vehicles	Value of vehicles assets (in log)	9.667	1.174
Super	Value of super assets (in log)	11.189	1.659
Temperature shocks			
Raw temperature	Average annual temperature (C degree)	16.916	2.863
Standardized	Temperature deviation divided by standard deviation.	0.102	0.788
Rainfall			
Rainfall	Average daily rainfall	0.002	0.001
Other variables			
Age	Age of household head	47.742	13.894
Year 11 and below	Equals 1 if highest educational attainment is Year 11 or lower	0.255	0.436
Year 12	Equals 1 if highest educational qualification is completing high school	0.111	0.314
Diploma / Certificate	Equals 1 if highest educational qualification is a diploma or Level III or IV certificate	0.353	0.478
Degree	Equals 1 if highest educational qualification is bachelor or higher degree	0.280	0.449
Single	Equals 1 if not married or living with someone in a relationship	0.380	0.485
Cohabiting	Equals 1 if not married, and living with someone in a relationship	0.490	0.500
Married	Equals 1 if married	0.129	0.336
Long-term health condition	Equals 1 if has health condition or disability that restricts everyday activity	0.266	0.442
Number of dependents	Number of dependents	0.581	1.003
Risk preference	Financial risk prepared to take; higher index means more risk averse.	2.194	3.418
Time preference	Financial planning horizon; higher index means higher time preference.	2.965	1.560

Notes: Monetary units are adjusted for inflation.

Table A2: Main results – Non-log transformation

Dependent variable	Net worth	
	Pooled OLS (1)	FE (2)
Temperature shock	43,103.712*** (14,752.045)	32,625.193** (13,279.843)
Observations	25,732	25,732
Controlling for rainfall	Yes	Yes
Postcode FE	Yes	Yes
Time FE	Yes	Yes

Notes: Robust standard errors in parentheses; standard errors are clustered at postcode level; *** p<0.01, ** p<0.05, * p<0.1

Table A3: Controlling for other covariates

Dependent variable	Net worth	Saving
	(1)	(2)
Temperature shock	0.043***	0.127**
	(0.014)	(0.050)
Rainfall	-18.613	199.634**
	(22.500)	(81.621)
Education (Ref. Higher degree)		
Year 11 and below	-0.303**	-0.223
	(0.129)	(0.429)
Year 12	-0.217*	-0.195
	(0.112)	(0.339)
Diploma / Certificate	-0.186**	-0.180
	(0.082)	(0.242)
Marital status (Ref. Married)		
Single	-0.331***	-0.571***
	(0.045)	(0.177)
Cohabiting	0.338***	-0.087
	(0.044)	(0.173)
Other variables		
Age	-0.018	-0.017
	(0.037)	(0.108)
Long-term health condition	-0.077***	-0.030
	(0.023)	(0.080)
Number of dependents	0.023*	-0.033
	(0.012)	(0.042)
Observations	25,723	7,078
Postcode FE	Yes	Yes
Time FE	Yes	Yes

Notes: Robust standard errors in parentheses; standard errors are clustered at postcode level; *** p<0.01, ** p<0.05, * p<0.1

Table A4: Alternative weather data

Dependent variable	Net worth	Saving
	(1)	(2)
Temperature shock	0.036***	0.097**
	(0.013)	(0.044)
Observations	17,984	7,364
Controlling for rainfall	Yes	Yes
Postcode FE	Yes	Yes
Time FE	Yes	Yes

Notes: Robust standard errors in parentheses; standard errors are clustered at postcode level; *** p<0.01, ** p<0.05, * p<0.1

Table A5: Sub-sample analysis (cold vs hot postcodes)

Dependent variable	Net worth		Savings	
	Cold	Hot	Cold	Hot
Temperature shock	0.021	0.055**	0.102	0.129*
	(0.027)	(0.023)	(0.091)	(0.074)
Observations	12,052	12,822	3,278	3,476
Controlling for rainfall	Yes	Yes	Yes	Yes
Postcode FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Notes: Robust standard errors in parentheses; standard errors are clustered at postcode level; *** p<0.01, ** p<0.05, * p<0.1

Table A6: Robustness to different fixed effects

Dependent variable	Net worth	Saving
	(1)	(2)
Panel A: State specific time trend		
Temperature shock	0.037**	0.124***
	(0.015)	(0.043)
Observations	25,980	7,434
Postcode FE	Yes	Yes
Year FE	Yes	Yes
State*Year linear	Yes	Yes
Panel B: District fixed effects		
Temperature shock	0.040***	0.151***
	(0.015)	(0.056)
Observations	20,673	5,533
District FE	Yes	Yes
Time FE	Yes	Yes
Panel C: LGA fixed effects		
Temperature shock	0.035**	0.134***
	(0.015)	(0.047)
Observations	25,931	7,388
LGA FE	Yes	Yes
Time FE	Yes	Yes
Panel D: Month of interview fixed effect		
Temperature shock	0.044***	0.129***
	(0.015)	(0.049)
Observations	25,732	7,078
Postcode FE	Yes	Yes
Time FE	Yes	Yes
Month of interview FE	Yes	Yes

Notes: Robust standard errors in parentheses; standard errors are clustered at postcode level; All regressions control for rainfall; *** p<0.01, ** p<0.05, * p<0.

Table A7: Quantile regression

Dependent variable	Net worth				Saving			
	OLS	Q25	Q50	Q75	OLS	Q25	Q50	Q75
Temperature shock	0.048**	0.069**	0.060***	0.026	0.114***	0.123***	0.133***	0.104***
	(0.023)	(0.035)	(0.017)	(0.017)	(0.035)	(0.045)	(0.035)	(0.033)
Observations	25,732	25,732	25,732	25,732	7,078	7,078	7,078	7,078
Controlling for rainfall	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Postcode FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors in parentheses; standard errors are clustered at postcode level; *** p<0.01, ** p<0.05, * p<0.1