The Value of Climate Hedge Assets: Evidence from Australian Water Markets *

Ryan Lewis†

June 19, 2023

[PRELIMINARY AND INCOMPLETE]

In Australia's Murray Darling Basin (MDB), short term (allocation) and long term (entitlement) water rights are separately traded, centrally reported, and disseminated to the public. I utilize this setting to demonstrate three primary findings concerning water rights and climate change risk. First, water rights appear to be a climate change hedge: in periods of diminishing supply, allocation cash flows spike as price increases offset quantity declines. Second, since 2014, entitlement prices in climate exposed areas have increased approximately $1500 per MegaLitre (about 39%) more than prices in non-climate exposed areas while allocation prices are similar in both areas. These price differences provide a clear market signal about future scarcity and help to define investment opportunities available today to preserve water resources. Finally, estimating the allocation cash-flow–rainfall elasticity and extrapolating using the 2050 IPCC rainfall scenarios, I attribute about 21% of the price effect to differences in expected cash flow, and the remainder to a lower discount rate. The premium I estimate equates to a 1.3% lower rate of return for climate hedge or mitigation assets, a critical parameter in climate economics.

KEYWORDS: Irrigation, Climate Change, Climate Resilience, Water Policy, Climate Policy.

*For insightful comments and questions, I thank Eric Alston, Asaf Bernstein, Andrea Buffa, Emily Gallagher, William Larson, Philip Mulder, and participants at the University of Colorado and the Office of Financial Research. Financial support for this research was generously provided by the Center for Ethics and Social Responsibility at the Leeds Business School at CU Boulder. All errors are my own.

†University of Colorado-Boulder. Email: ryan.c.lewis@colorado.edu.

1 Introduction

Financial markets will play an important role in shaping the world's response to climate change for at least three reasons. First, to the extent price acts as an informative public signal, accurate pricing of climate related risks should help to direct private investment and adaptation. Second, the discount rate applied to climate exposed or climate hedge assets is critical to guide public investment climate mitigation and appears as a key parameter in climate models. Finally, when prices reflect the underlying risks, trade can help to facilitate efficient allocation of climate related risk, with those who are less concerned or more able to bear exposure to climate change purchasing exposed assets.[1] While existing research documents the pricing of physical climate risk in many markets,[2] these dynamics are perhaps most relevant for water resources, where climate change directly threatens already unsustainable usage in many regions.[3] Establishing sustainable practices today can help prevent water crises in the future, and information gained from this directly threatened and vital commodity is relevant to climate policy generally.

Assessing asset market responses to climate risk exposure requires overcoming two broad challenges. First, separating the *future* climate risk exposure from current risk is difficult because most climate change related risk is highly correlated with hazard risk today (Dell, Jones, and Olken (2014)). Existing research has focused on a narrow set of climate risks to overcome these challenges, and this research is largely limited to identifying the price discount for assets that are negatively exposed to climate risk. Second, shocks to either the underlying climate change risk or perception of an assets climate change risk are often correlated with cash flow effects today (e.g. Addoum, Eichholtz, Steiner, and Yönder (2021) uses Hurricane Sandy to provide identification based on salient events) which directly impact

1. As in Bakkensen and Barrage (2021) and Bernstein, Billings, Gustafson, and Lewis (2022))

2. Specifically, climate risk appears priced in in real estate (Bernstein, Gustafson, and Lewis (2019), Baldauf, Garlappi, and Yannelis (2020), Keys and Mulder (2020)—with some counter evidence using subsidence measures by Murfin and Spiegel (2020)) and municipal bonds, Painter (2020) and Goldsmith-Pinkham, Gustafson, Lewis, and Schwert (2022), but not in equity marketsHong, Li, and Xu (2019)

3. See e.g. Arnell (1999); Vörösmarty, Green, Salisbury, and Lammers (2000); Mankin, Viviroli, Singh, Hoekstra, and Diffenbaugh (2015); Milly and Dunne (2020)

the value of long lived assets.

In Austrailia's Murray Darling Basin (MDB), water assets are separable (long term entitlements and short term allocations trade independently), actively traded, and centrally disseminated. I utilize this setting to overcome the above identification challenges and deliver three novel insights regarding climate change risk and water market. First, entitlement rights act as a climate change hedge. When supply declines, prices spike and short term cash flows increase. Second, since 2014, entitlement prices in such climate exposed areas have increased over \$1500 per MegaLitre (about 39%) more than prices in non-climate exposed areas while allocation prices are similar in both areas. Finally, estimating the allocation price–rainfall elasticity and extrapolating using the 2050 Intergovernmental Panel on Climate Change (IPCC) rainfall scenarios, I attribute about one fifth of the price difference to differences in expected cash flow, and the remainder to a lower discount rate for climate hedge assets.

The Water Act of 2007 in Australia is a comprehensive piece of legislation aimed at providing a sustainable framework for managing water resources and addressing the long-term impacts of over-allocation, climate change, and drought on the country's water systems, particularly in the Murray-Darling Basin. The Act was implemented in response to growing concerns about water scarcity, environmental degradation, and the need for a more integrated approach to water resource management. It built upon previous legislation, such as the Murray-Darling Basin Agreement (1987) and the National Water Initiative (2004), by establishing the Murray-Darling Basin Authority, which is responsible for developing and implementing the Basin Plan, setting sustainable diversion limits, and overseeing water trading rules. The Water Act 2007 also promoted water conservation, efficiency measures, and the use of environmental water to support ecological health.

Before these reforms, water rights mirrored those in the US West. They were often tied to land ownership and lacked proper environmental considerations, leading to over-allocation and unsustainable extraction. These legislative efforts lead to two major changes in the regulation of water rights. First, they established a clear separation of water rights from land titles, facilitating the establishment of a robust water market. These rights are tradeable as both water entitlements—perpetuity claims to allocation each year—and seasonal allocations, thereby allowing water to be reallocated to users with higher value or to support environmental needs during periods of abundance. The Murray-Darling Basin Authority, under the Water Act 2007, is also responsible for overseeing trading rules and monitoring activity, which is collected at the state level and distributed through the Australian Government's Bureau of Meteorology.

I utilize this comprehensive market information to overcome the basic challenges to identifying the pricing of long-term climate risk as follows. First, in the absence of allocation price controls, I document an economically and statistically significant elasticity between long lived entitlement claims and short run weather effects. In fact, a weather shock that increases allocation revenue by one dollar increases entitlement prices by approximately \$50. Without controlling for short term prices, researchers might incorrectly conclude that weather variability causes long run asset holders to update beliefs about future rainfall. Once I include allocation price controls, the contemporaneous relationship between weather and entitlement prices dissipates. The MDB setting allows a research design that disentangles factors that affect both short- and long-term prices from those that only impact the infinitely lived entitlements.

In the main analysis, I document a substantial relative price appreciation for long term entitlement claims in areas that are exposed to risk of reduced runoff due to climate change, as described by the 2014 regional IPCC report. Entitlement prices in areas with above median runoff risk begin to diverge from those with below median risk in 2015. By 2021, climate exposed entitlements trade for close to \$1500, or 30% more per megalitre. Consistent with the pricing of future cash flows, allocation prices over the same window stay similar between the two exposure groups.

While both allocations and entitlements are freely tradeable within a catchment zone, moving water across zones is prohibitively costly. Thus climate risk exposure is well defined at a local geographic level without concerns of reallocation across zones. However, economic spillovers may be present that could alter conclusions of the analysis. For example, expectations of future reduced runoff in one area that grows wheat, may spillover to other areas that also grow wheat and indirectly drive water prices in the places not projected to experience reduced runoff. To address these concerns I utilize geographic information on local area farm production. Australia splits the country into similar growing regions called Australian Broadacre zones and regions, which due to their management by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), are called ABARES regions. These regions generally span multiple catchment areas. I construct "leave out" controls for allocation and entitlement prices within each catchment's ABARES and find the price difference drops by approximately 30% in response to these controls. I find a similar drop when I divide the sample into ABARES x Catchment units and control for ABARES x Time fixed effects. Economic spillovers do seem to drive some of the pricing effect, but after accounting for each economic region's trend, entitlement prices in exposed regions have are still over $1000 per Megalitre higher than non-exposed areas.

In the final analysis, I leverage the unique nature of the MDB data which allows me to decompose the price effect into two components, projected cash flow differences and discount rate changes. This analysis requires three pieces of information: (1) the prices for climate exposed and non-exposed entitlement claims, (2) an estimate of the seasonal cash flow elasticity to natural water supply, and (3) the projected reduction in water supply in the future across catchment areas. I can then calculate the difference in internal rate of return between owning climate exposed and unexposed assets.

For (1), i start with the 2021 median price for non-climate exposed entitlements of $3500 per ML. I add to this the estimated $1500 increase for climate exposed rights to get a price of $5000. To estimate (2), I run a simple linear regression that relates seasonal allocation prices to rainfall amounts in each catchment. An 1% decrease in rainfall results in a 1.4%

increase in prices. The results deliver an elasticity consistent with Brennan (2006). When I add in the actual received allocations, I find that cash-flows increases by 1.3% for each percent decrease in rainfall. For item (3), I take seriously the runoff projections from the IPCC report. Above median climate exposed catchments are expected to have a relative decrease of approximately 17% due to decreased supply as compared with 3% for the non exposed. To complete the analysis, I assume a linear transition path and a steady state achieved in 2050.

The IRR for non-climate exposed claims is 5.3% based on average cash-flows to the entitlement claims. For climate exposed entitlement rights I calculate an IRR of 4%. This 1.3% difference directly relates to the discount rate differences for climate hedge assets which is modeled in Giglio, Kelly, and Stroebel (2021). To further decompose the IRR difference, I estimate an NPV of $3822 for the climate exposed entitlement cash flows using the IRR for non-climate exposed. Thus approximately one fifth of the difference in prices can be attributed to cash flows and the other four fifths to differences in discount rates. Climate exposed water rights that are projected to deliver higher cash-flows when climate change decreases water supply provide a hedge against climate risk and therefore trade at a lower expected return.

1.1 Literature Review

This paper touches on a broad literature in environmental and climate economics as well as finance. As such, the literature review will likely not do justice to all relevant papers.[4] However, I will focus on three main topics. First, there is significant work that attempts to estimate the price of climate change risk across multiple asset classes. Second a broad literature examines the pricing dynamics of water resources with some papers specifically focused on the MDB. Lastly, a wealth of papers focus on natural science models of climate change and project likely risks. While not directly relevant to the analysis here, I implicitly

4. Please do not hesitate email ryan.c.lewis@colorado.edu and let me have it if I neglected an important or even remotely relevant cite

leverage these models.

This paper relates to climate finance and economics along two primary dimensions. First, I establish that market participants are willing to pay a premium for assets that are likely to pay out when climate change is worse. Numerous papers in the field establish that actors pay a discount for assets that appear to be negatively exposed to climate risk. Bernstein, Gustafson, and Lewis (2019) and Baldauf, Garlappi, and Yannelis (2020) establish a discount for properties exposed to sea level rise while Murfin and Spiegel (2020) shows that subsidence (a particular component of coastal flood risk) does not appear to be priced. Moreover, municipal bonds appear to price coastal flood risk as evidenced by Painter (2020) as well as *future* sea level rise risk sd in Goldsmith-Pinkham, Gustafson, Lewis, and Schwert (2022). Moreover, Bernstein, Gustafson, and Lewis (2019); Bernstein, Billings, Gustafson, and Lewis (2022); Keys and Mulder (2020) demonstrate that the price of climate risk varies according to beliefs, generating a substitution as predicted by Bakkensen and Barrage (2021). Finally, Hong, Li, and Xu (2019) suggests that there does not appear to be a large impact of drought exposure on equity markets.

Second, in all above cases the cash flow loss or utility cost of climate exposure is inferred but not directly measured. In water markets, precipitation, and by extension runoff supply are directly linked to the cash flows available to water rights assets. The extent of "exposure" is not inferred in reduced form and the cash flow elasticities can be measured from historical data. This unique feature of water markets data make identification simpler and allows me to back out the discount rate component of the premium directly from the data instead of using a structural asset pricing model as in Giglio, Maggiori, Rao, Stroebel, and Weber (2021a).

Outside of physical risk, a large literature exists on the price of transition risk. Here the evidence is mixed. Bolton and Kacperczyk (2021) argue that high emission firms are already displaying a risk premium through higher returns, while Pastor, Stambaugh, and Taylor (2022) show that "brown" firms appear to have *under-performed* "green" over the past 15 years indicating that future risk premiums are high. Lastly, Berk and van Binsbergen (2021) argue that there appears to be very little price impact in either direction for "brown" firms.

A vast literature exists that examines the pricing of water claims across various markets. While not the first paper on the topic, Rimsaite, Fisher-Vanden, Olmstead, and Grogan (2021) is most relevant as it attempts to measure the amount of long run economic information in water rights prices. It builds on a rich catalogue of water markets papers which examine formalized water market prices in various regions such as California Hagerty (2019); Bruno and Jessoe (2019), south Texas Chang and Griffin (1992), southern Italy and Spain Pujol, Raggi, and Viaggi (2006); Rey, Garrido, and Calatrava (2014), north-central Chile Hearne and Easter (1997); Hearne and Donoso (2014), Morocco Diao and Roe (2003), and Australia Bjornlund and McKay (2002); Tisdell (2014); Wheeler, Bjornlund, and Loch (2014); Zuo, Yang, Zhong, Chen, and Wang (2015); Grafton, Horne, and Wheeler (2016); Loch, Wheeler, and Settre (2018). In most cases these studies document large gains from trade from instituting formalized water markets. Moreover, Australia has served as a blueprint for reforms in other US basins like Nevada's Diamond Valley and Humboldt Basin. My contribution to this literature is to examine the extent to which these markets price long term climate risk in addition to the myriad other factors that drive water market prices.

Lastly, I leverage the existing natural science work that projects basin stress and runoff changes due to climate risk. In particular I utilize the information provided in the 2014 IPCC report on climate risk for the Australasia subregion Reisinger, Kitching, Chiew, Hughes, Newton, Schuster, Tait, and Whetton (2014). The data there are based on other studies of the region such as: Chiew and Prosser (2011); Teng, Chiew, Vaze, Marvanek, and Kirono (2012).

2 Setting: The Water Act of 2007 and related legislation

The legislation leading up to the Water Act of 2007 has its origins in the early 1990s, when Australia faced an unprecedented water crisis. The severe drought conditions and increasing demand for water resources led to the Council of Australian Governments (COAG) initiating a series of water reforms. In 1994, COAG established the National Water Initiative (NWI), which aimed to improve the efficiency of water use and promote sustainable water management. This was followed by the 2004 National Water Initiative Agreement, which provided a comprehensive framework for water policy and set objectives for integrated water management across the country.

The NWI Agreement was signed by the Australian government and all state and territory governments, with the exception of Western Australia and Tasmania, who joined later in 2006 and 2008, respectively Australian Government (2011). It aimed to achieve a more cohesive and sustainable approach to managing water resources in Australia in response to increasing water scarcity, climate change impacts, and the need for efficient water allocation. It contained several key objectives including 1) The establishment of clear and nationally compatible water access entitlements and planning frameworks to provide security and certainty for water users and the environment. 2) The promotion of efficient and sustainable water use by encouraging the development of water markets and trading across state boundaries, with the goal of allowing water to be allocated to its highest-value use. 3) Ensuring that water is allocated and used efficiently in urban and rural areas, and encouraging the adoption of best management practices for water infrastructure, including cost-reflective pricing and demand management strategies. Most important for the puroses of this study were 1 and 2, which laid the groundwork for subsequent formalization of water trading markets through future legislation.

The Water Act of 2007 represents a second major milestone in the Australian water reform journey, building upon the foundation established by the previous initiatives. The Act established the Murray-Darling Basin Authority (MDBA) to manage the water resources of the Murray-Darling Basin, the most significant agricultural region in Australia. The Act also set out the legislative framework for the development of the Basin Plan, which outlines the long-term sustainable management of the water resources in the region, including the setting of sustainable diversion limits and the establishment of water trading rules.

One of the key features of the Water Act of 2007 is the introduction of the concept of the separability of water rights. Under this principle, water rights are unbundled from land titles, allowing for the separation of water access entitlements from land ownership. This has facilitated the creation of a more efficient water market, enabling water entitlement holders to trade their allocations freely. The introduction of water trading markets has encouraged a more efficient allocation of water resources, as it allows water to be transferred from lower-value uses to higher-value uses, ultimately benefiting both the economy and the environment.

The consequences of this string of legislation, particularly the Water Act of 2007, have been transformative for water management in Australia. The creation of water trading markets and the separability of water rights have led to increased efficiency in water allocation and use, while also providing greater flexibility for water users to adapt to changing conditions such as droughts or fluctuating market prices. The introduction of sustainable diversion limits has also helped to ensure the long-term health of the Murray-Darling Basin, by preventing over-extraction of water resources. Overall, these legislative efforts have been instrumental in establishing a more sustainable and resilient water management system for Australia's vital water resources.

3 Data

I obtain data from multiple sources. First, as noted above, The Act provided empowered the Australian Bureau of Meteorology (BOM) to collect and report water transactions reporting from states that were part of within the Murray Darling Basin. These transactions contain many details regarding the details of the water right, but broadly there are 7 pieces of information that I utilize. The transaction records price, quantity (in mega litres), trade type (e.g. whether it is a partial transfer of entitlement or a full transfer), tenure (in almost all trades these are permanent), the resource type (e.d. ground or surface), the destination (I utilize the catchment level of granularity), the reliability (determines the priority structure of allocations), and whether it is a regulated or unregulated water resource. Starting in 2008, I observe entitlement claims trades for the majority of catchments in the sample, though a few areas don't start reporting until 2009. Allocation trades follow a similar setup, except that the tenure is always a single year, and the reliability is not specified (individuals can only trade allocation claims that they have already received for that water season).

I clean the allocation and entitlement data in a couple of ways. First, following (Wheeler, Loch, Zuo, and Bjornlund (2014)) I exclude all transactions where the price per megalitre was above or below the 95th pctl or ¿ 31,667 and ¡ 40 and ¿ 10,000 and ¡ 10 for the entitlement market and allocation markets respectively. Next I exclude trades where the amount traded is less than or equal to 1 megalitres. I end the cleaning here, though note that the authors suggest additional smoothing measures depending on the application. The results are robust to excluding outliers beyond the moving average for each catchment.

I then match the allocation and entitlement transactions within the water market data, which is simple due to the uniformity of the catchment data across both markets. Figure 3 displays the time series trend of allocation and general reliability entitlement prices across the MDB, equally weighted across catchments. While allocation prices remain relatively steady across the sample period, entitlements have jumped in price since 2014, and are 200% percent higher today than in the beginning of the sample. Tables 1 and 2 display the sample statistics at the trade level for both markets.

Next I merge water trading data to multiple sources of geographic information. To match to local weather and rainfall patterns, I identify the latitude and longitude of "reliable" weather stations with at least 99% up-time from the Australian Bureau of Meteorology (BOM). I download historical monthly precipitation data from each of the 953 such stations. Figure 1 displays the stations used overlaid on a catchment map of Australia. In addition, I identify the location of water storage facilities and obtain capacities and historical storage amounts for these storage areas.

The weather station and water storage facility represent the finest geographic measures. I merge these data into two additional sources of geographic information. First, I obtain data on water catchment which are provided as geographic shapefiles by the BOM zones. These I then hand match the geographic zone at the catchment level to the trading data provided by the MDB authority.

Second, I include match to data on Australian Broadacre zones and regions (ABARES). These large zones are defined by the type of farm production and the climate regions. Importantly, the Department of Agriculture, Fisheries and Forestry supplies both the geographic boundaries for each of these zones as well as annual economic activity for the farms located within each zone.

To identify the incidence of climate risk at the catchment level, I first utilize the median scenario runoff deterioration map from the 2014 IPCC regional report on Australia. Figure 2 displays this may with catchments overlaid. The map color codes the expected decrease in runoff continuously across Australia. To merge the data, I identify the expected runoff differential in 2050 at each weather station. I then take the equally weighted average across stations with the broader catchment area. On average, catchments in the sample expect to see a deterioration of 10% amount of runoff by 2050. the measure is consistent with the MDB plan studies which project a larger runoff decrease in the southern MDB. In the internet appendix, I consider additional measures that take into account the various climate scenarios as well as those that treat "White" areas according to the broad north vs south delineation for climate effects.

4 Results

As noted above, Australian water markets are unique across many dimensions that permit establishing a clean link between climate change risk and asset prices. Notably, the underlying claims are directly linked to climate outcomes, and, as I show below, will likely serve as a hedge against climate change risk. In addition, the current use "dividend" is separately priced from the long run claim allowing me to strip out long from short run expectations. Lastly, allocation supply is primarly driven by unpredictable weather patterns, allowing me to separate supply and demand effects in the short term market.

The analysis has three major components. First, I characterize water market prices and how they relate to contemporaneous rainfall shocks. Next I investigate whether and how climate change forecasts drive prices. Third I decompose climate effects into the discount rate and cash flow components.

4.1 Dynamics of Water Markets

I begin by examining the drivers of water prices in both the entitlement (long lived) and allocation (one year) markets. Each year, an entitlement holder is given an allocation based on their entitlement amount. In a high water year, all entitlements may receive a full allocation with overflow allocated to environmental considerations. In worse years where runoff is low, entitlements may only receive a partial allocation. In these years, entitlements with high "reliability" will receive their allocations first, followed by those with "general" or "low" reliability. Once allocations are meted to entitlement holders, they are free to either trade or use their allocated amount. In this section, I examine the interrelations between rainfall, quantity distributed, and prices in the allocation and entitlement markets.

First, I demonstrate a significant, and unsurprising positive relationship between proportion allocated and average station rainfall within a catchment area. In table 3, Panel A, column 1, I examine these relationships at the catchment level. I run regressions of the following form:

$$Alloc_{ct} = \alpha_c + \beta Precip_{ct} + e_{ct}$$

Where $Alloc_{ct}$ is the minimum cumulative catchment allocation amount in a water year, $Precip_{ct}$ is the rolling average precipitation in catchment c for water year t.

Column (1) demonstrates that decreased rainfall within a catchment area has an economically and statistically significant impact on average water distributions for entitlement claims. Rainfall years 1 cL below average are associated with 0.5% percent decreased distribution. Column (2) investigates the impact of rainfall on prices, showing that an 1 cL decrease in rainfall has a 38 cent increase in allocation prices. Finally, Column (3) combines prices and allocations to show that a 1 cL decrease in rainfall increases cash-flow by 16 cents per ML. Estimated in a log - log elasticity, I find that a 1 percent decrease in rainfall increases entitlement cash flows by 1.3%. This last estimate that shows a large increase in cash-flows when water is scarce will form a key building block to estimate the long term discount rate effects in this market.

4.2 Climate Risk and Climate Hedge Value

A compelling empirical analysis that estimates the price of climate change related risk must overcome at least three obstacles. First, the analysis must identify a long lived asset that is exposed to climate change risk and compare that to a control asset that is less or non-exposed. With water markets, this criteria is clearly met. Water supply is directly exposed to climate change through both changing weather patterns and increased temperatures, making water assets a suitable candidate. Moreover, since climate scientists predict meaningful variation in aggregate runoff effects across Australia, this setting provides a clear treatment and control group for the analysis.

Second, the analysis must clearly differentiate between current and long term risk. In many previous studies that estimate a price of climate change risk (e.g. those that examine real estate and equity markets) I do not observe a price for both the short and long term claim on the same underlying asset. Because MDB water trades in both the allocation and entitlement markets, and the allocation claim is distributed on the exact underlying entitlement, these markets allow me to directly control for any observable and unobservable effects that can drive the price of both claims.

I illustrate the importance of having data on allocation prices in Table 3 Panel B. Here

I run regressions of the following form:

$$p_{it} = \gamma rm + \beta^1 Precip_{ct} \beta^2 Storage_{ct} + \beta^3 Price^a lloc_{ct} + e_{it}$$

In Columns (1) and (3) I demonstrate that, in response to seasonal decreases in rainfall or storage at the catchment level, I observe a increase in long term entitlement prices. For a one percent decrease in storage amounts, entitlements increase by \$5.78. Similarly for a one cL decrease in rainfall, entitlement prices increase by \$6.37.

Given this result, one might incorrectly conclude that seasonal weather patterns impact long term allocation claims. In columns (2) and (4) I include controls for contemporaneous allocation prices. In these regressions the impact of seasonal rainfall on entitlement claims disappears—all of the relation is driven by fluctuations in near term allocation prices. Because near term events spill over into long term prices, any shock (e.g. salience of extreme weather events) that has a near term price effect may be incorrectly interpreted as driving the price of long term climate assets.

The last hurdle in establishing the price effect of climate risk is to control economic linkages that may hinder the interpretation of a coefficient. While water itself is not portable across catchments, the productive decisions of other agricultural producers may spillover. Here, Australia provides useful data that separates geographic areas by their key productive attributes, which I will use in later regressions to refine the estimates.

the first analysis to demonstrate the price of climate change risk in water markets is evident in Figures 4 and 5. Here I plot the yearly estimates from regressions of the following form:

$$p_{it} = \gamma_{rm} + \sum_{y=2007}^{2018} \beta_y \mathbf{1}_{it}^y + e_{it} \tag{1}$$

where p_{it} is the price per megalitre for the allocation transaction, γ_{rt} represents fixed effects for the seasonal characteristics of the allocation and entitlement transaction (month x catchment x trade type x resource type x regulated x reliability). I estimate the effect for climate exposed and non-climate exposed separately, and plot them for each market.

These figures combine to provide two takeaways. First, allocation prices between climate exposed and non-climate exposed regions have remained stable and tightly bound for the entire sample. In periods of country wide drought, these prices jump up, but these droughts appear to be unrelated to climate change risk exposure. Second, when I compare climate exposed vs non-exposed general reliability *entitlement* claims, I observe a price wedge between the climate exposed and non-exposed claims starting in 2015 and expanding thereafter. Areas that are predicted to suffer from decreased runoff due to climate change see substantial increases in their allocation prices in the last five years of the sample.

As shown in Section 4.1, water asset prices increase when runoff falls, these climate exposed water claims are a unique asset in the global economy: they provide a hedge against regional climate change risk. As such, it is not surprising that the price of these claims has increased during a period when many climate risk assets have experienced price declines.

Table 4 substantiates the results from Figure 4, estimating on a combined sample where the yearly indicator is interacted with an indicator for above median climate exposure. Again, the results are clear: the price per megalitre in climate exposed regions is approximately \$1500 more at the end of the sample across a variety of specifications. The coefficient remains fairly stable as we move from the uncontrolled regressions to those with higher dimensional fixed effects and finally after we include controls for contemporaneous allocation prices. This last addition is somewhat unique to water markets — we can include a control for the short term asset value when estimating the climate impact of the long term claim. [5]

This table addresses the first two obstacles to identifying the impact of climate change risk/hedge value in asset prices. Next, I attempt to address the third concern along two dimensions. First, I identify and control for the price of entitlement and allocation claims in economically linked, proximate geographic areas, ABARES. As noted in Section 3, ABARES regions are large areas which are related in production decisions. Notably, ABARES regions

5. While real estate markets, where climate effects have previously been successfully studied have rental indices, they are more general and not applicable to the whole sample.

do not perfectly overlap with catchments and are often much larger zones.

To calculate price controls, I first calculate the price for both allocations and entitlements at each station based on its catchment area. Then for each catchment, I sample all of the stations within a broader ABARES region which are not in a particular catchment. I then take the average entitlement and allocation price for all relevant stations within the ABARES region. If a catchment spans multiple ABARES regions, I take the station weighted average of each relevant region.

Columns (1) and (2) of Table 6 display the results for the benchmark specification after controlling for entitlement and allocation prices. Here we comnbine the years into a pre and post period for statistical power. Interestingly, the price of entitlements across regions appears to spill over through economic linkages. In fact, this spillover effect appears to account for approximately 25% of the overall effect I observe. Notably, controlling for allocation prices within a catchment does not reveal a similar spillover, indicating that the spillovers are reflecting expectations about future water prices.

In the last robustness test I split the observations into catchment x ABARES units. I then estimate an ABARES region by time fixed effect. This absorbs any time varying economic factors that drive prices within any economic regions. Here I recover a coefficient that is approximately equal to that which results after I control for adjacent entitlement prices. However, the precision of the estimate increases measurably. Controlling for economic cross-linkages eliminates much of the noise in the estimate. As such, I will use this last column as the best identified and most economically meaningful coefficient.

4.3 Climate Related Discount Rates

To tie the analysis together, I utilize the unique feature of water markets—that cash flows can be estimated directly in proportion to rainfall or water supply—to shed light on an important debate in the environmental economics literature on climate change policy: what discount should we apply to assets or investments that reduce climate damages? This question is implicitly the same as asking what discount rate should the social planner use for climate damages generally, and this parameter has vast consequences for the ideal amount of investment today. In fact, this parameter may be the most important that goes into any climate model.

Numerous estimates of this discount rate are used, with Giglio, Maggiori, Rao, Stroebel, and Weber (2021b) suggesting a rate that is actually substantially lower than the long term discount rate they estimate of 2.8%. To identify the adjustment to the risk free long term discount rate, they utilize a standard insight from asset pricing: that assets with low or negative betas have lower expected returns. But "how much lower" is simply inferred in their analysis by assuming the beta of climate hedge assets. In the following analysis, I directly estimate the discount rate difference based on scientific projections of runoff, current entitlement prices, allocation cash-flows, and the sensitivity of allocation cash-flows to changes in rainfall.

The analysis is a simple IRR calculation using the following parameters. The scientific projection for runoff percent changes I estimate from the IPCC Australasia report. On average, climate exposed (CC) catchments in my sample are set to see a 17% decrease in runoff vs 3% for non climate exposed (non-CC). The average cash flows for both CC and non-CC are the same for the sample period at $180 per ML. I estimate a $1,500 price premium for CC entitlements in 2021, compared with a median price for entitlements in non-CC areas of $3,500 in 2021. Lastly, I estimate a cash-flow– rainfall elasticity of -1.4, so a 1% decrease in rainfall increases cash flows by 1.4%. This estimate is consistent with Brennan (2006).

To project cash-flows, I begin with the sample average of $180 per ML for 2021. I then assume a linear transition path to 2050 using the different scientific projections for CC and non-CC. I assume that the 2050 precipitation amounts become the steady state. I then run a standard IRR calculation to solve for the discount rate for CC and non-CC entitlements. I find that CC cash flows imply a discount rate of 4.1% given the estimated price of \$5,000, while non-CC implies a discount rate of 5.3%. Importantly some of this difference is attributable to the difference in cash-flows between the two entitlement. As such I also calculate an NPV of \$3,817 for the cash flows of the CC entitlement using the discount rate of the non-CC entitlement of 5.3%. As such I attribute 21% of the difference in price to cash flows and 79% to discount rates. Relating this to Giglio, Maggiori, Rao, Stroebel, and Weber (2021b) I estimate an implied discount rate premium for climate hedge assets of 1.3%. Using the framework of Giglio, Maggiori, Rao, Stroebel, and Weber (2021b), this implied a discount rate of 1.9% for climate damages.

5 Conclusion

In conclusion, this study highlights the critical role that asset markets play in responding to climate change, particularly in the context of water resources. The Australian Murray-Darling Basin serves as an ideal setting to examine the pricing of long-term climate risk and its effect on water asset markets. By utilizing comprehensive market information and addressing the challenges of identifying the pricing of long-term climate risk, the research delivers three novel insights into the relationship between climate change risk and water markets.

First, the findings demonstrate that water entitlement rights act as a climate change hedge, providing protection against the financial risks associated with climate change. Second, the study reveals that entitlement prices in climate-exposed areas have increased significantly compared to non-climate exposed areas, while allocation prices remain similar. This suggests a growing separation between water users and entitlement owners in climate-exposed regions. Lastly, the research attributes approximately one-fifth of the price difference to differences in expected cash flow, with the remainder due to a lower discount rate for climate hedge assets.

The results of this study underscore the importance of effective policy and legislation, such as Australia's Water Act 2007, in creating sustainable frameworks for managing water resources in the face of climate change. The establishment of a robust water market, the separation of water rights from land titles, and the oversight of water trading rules have facilitated the effective pricing and allocation of climate risk. As the world continues to grapple with the challenges posed by climate change, the insights derived from this research can help inform the development of sustainable practices and policies that ensure the long-term resilience of water resources and the communities that depend on them.

References

Addoum, Jawad M, Piet Eichholtz, Eva Steiner, and Erkan Yönder, 2021, Climate change and commercial real estate: Evidence from hurricane sandy, *Available at SSRN 3206257*.

Arnell, N. W., 1999, Climate change and global water resources, *Global Environmental Change* 9, S31–S49.

Australian Government, National Water Commission, 2011, Strengthening australia's water markets, Discussion paper, .

Bakkensen, Laura A, and Lint Barrage, 2021, Going Underwater? Flood Risk Belief Heterogeneity and Coastal Home Price Dynamics, *The Review of Financial Studies* 35, 3666–3709.

Baldauf, Markus, Lorenzo Garlappi, and Constantine Yannelis, 2020, Does climate change affect real estate prices? only if you believe in it, *Review of Financial Studies* 33, 1256–1295.

Berk, Jonathan, and Jules H van Binsbergen, 2021, The impact of impact investing, .

Bernstein, Asaf, Stephen B Billings, Matthew T Gustafson, and Ryan Lewis, 2022, Partisan residential sorting on climate change risk, *Journal of Financial Economics* 146, 989–1015.

Bernstein, Asaf, Matthew T Gustafson, and Ryan Lewis, 2019, Disaster on the horizon: The price effect of sea level rise, *Journal of Financial Economics* 134, 253–272.

Bjornlund, Henning, and Jennifer McKay, 2002, Aspects of water markets for developing countries: experiences from australia, chile, and the us, *Environment and Development Economics* 7, 769–795.

Bolton, Patrick, and Marcin Kacperczyk, 2021, Do investors care about carbon risk?, *Journal of Financial Economics* 142, 517–549.

Brennan, D., 2006, Water policy reform in australia: lessons from the victorian seasonal water market, *The Australian Journal of Agricultural and Resource Economics* 50, 403–423.

Bruno, EM, and KK Jessoe, 2019, Water markets and climate change adaptation: micro-level evidence on agricultural water demand, *Working Paper, University of California, Berkeley*.

Chang, C., and R.C. Griffin, 1992, Water marketing as a reallocative institution in texas, *Water Resources Research* 28, 879–890.

Chiew, Francis, and Ian Prosser, 2011, Water and climate, *SCIENCE AND S* p. 29.

Dell, Melissa, Benjamin F Jones, and Benjamin A Olken, 2014, What do we learn from the weather? the new climate-economy literature, *Journal of Economic literature* 52, 740–798.

Diao, Xinshen, and Terry L Roe, 2003, Can a water market avert the" double-whammy" of trade reform and lead to a" win-win" outcome?, *Journal of Environmental Economics and Management* 45, 708–723.

Giglio, Stefano, Bryan Kelly, and Johannes Stroebel, 2021, Climate finance, *Annual Review of Financial Economics* 13, 15–36.

Giglio, Stefano, Matteo Maggiori, Kunal Rao, Johannes Stroebel, and Andreas Weber, 2021a, Climate change and long-run discount rates: Evidence from real estate, *The Review of Financial Studies* 34, 3527–3571.

Giglio, Stefano, Matteo Maggiori, Krishna Rao, Johannes Stroebel, and Andreas Weber, 2021b, Climate Change and Long-Run Discount Rates: Evidence from Real Estate, *The Review of Financial Studies* 34, 3527–3571.

Goldsmith-Pinkham, Paul, Matthew Gustafson, Ryan Lewis, and Michael Schwert, 2022, Sea level rise and municipal bond yields, *Yale University Working Paper*.

Grafton, RQ, J Horne, and SA Wheeler, 2016, On the marketisation of water: Evidence from the murray-darling basin, australia, *Water Resources Management* 30, 913–926.

Hagerty, N, 2019, Liquid constrained: estimating the potential gains from water markets, *University of California, Berkeley. Working Paper*.

Hearne, Robert, and German Donoso, 2014, Water markets in chile: Are they meeting needs?, *Water Markets for the 21st Century. Global Issues in Water Policy* 11, 103–126.

Hearne, Robert R, and K William Easter, 1997, The economic and financial gains from water markets in chile, *Agricultural Economics* 15, 187–199.

Hong, Harrison, Frank Weikai Li, and Jiahua Xu, 2019, Climate risks and market efficiency, *Journal of Econometrics* 208, 265–281.

Keys, Benjamin J, and Philip Mulder, 2020, Neglected no more: Housing markets, mortgage lending, and sea level rise, Discussion paper, National Bureau of Economic Research.

Loch, A, S Wheeler, and C Settre, 2018, Private transaction costs of water trade in the murray-darling basin, *Ecological Economics* 146, 560–573.

Mankin, J. S., D. Viviroli, D. Singh, A. Y. Hoekstra, and N. S. Diffenbaugh, 2015, The potential for snow to supply human water demand in the present and future, *Environmental Research Letters* 10, 114016.

Milly, P. C. D., and K. A. Dunne, 2020, Colorado river flow dwindles as warming-driven loss of reflective snow energizes evaporation, *Science* 367, 1252–1255.

Murfin, Justin, and Matthew Spiegel, 2020, Is the risk of sea level rise capitalized in residential real estate?, *Review of Financial Studies* 33, 1217–1255.

Painter, Matthew, 2020, An inconvenient cost: The effects of climate change on municipal bonds, *Journal of Financial Economics* 135, 468–482.

Pastor, Lubos, Robert F Stambaugh, and Lucian A Taylor, 2022, Dissecting green returns, *Journal of Financial Economics* 146, 403–424.

Pujol, Joan, Meri Raggi, and Davide Viaggi, 2006, The potential impact of markets for irrigation water in italy and spain: a comparison of two study areas, *Australian Journal of Agricultural and Resource Economics* 50, 361–380.

Reisinger, Andy, Roger L Kitching, Francis Chiew, Lesley Hughes, Paul CD Newton, Sandra S Schuster, Andrew Tait, and Penny Whetton, 2014, Australasia, in *Climate change 2014: Impacts, adaptation and vulnerability: Part B: Regional aspects: Working group II contribution to the fifth assessment report of the intergovernmental panel on climate change* . pp. 1371–1438 (Cambridge University Press).

Rey, David, Alberto Garrido, and Javier Calatrava, 2014, Water markets in spain: Meeting twenty-first century challenges with twentieth century regulations, *Water Markets for the 21st Century. Global Issues in Water Policy* 11, 127–147.

Rimsaite, Renata, Karen Fisher-Vanden, Sheila Olmstead, and Danielle S Grogan, 2021, How well do us western water markets convey economic information?, *Land Economics* 97, 1–16.

Teng, Jin, FHS Chiew, Jai Vaze, Steve Marvanek, and DGC Kirono, 2012, Estimation of climate change impact on mean annual runoff across continental australia using budyko and fu equations and hydrological models, *Journal of Hydrometeorology* 13, 1094–1106.

Tisdell, John, 2014, The evolution of water legislation in australia, *Water Markets for the 21st Century. Global Issues in Water Policy* 11, 163–178.

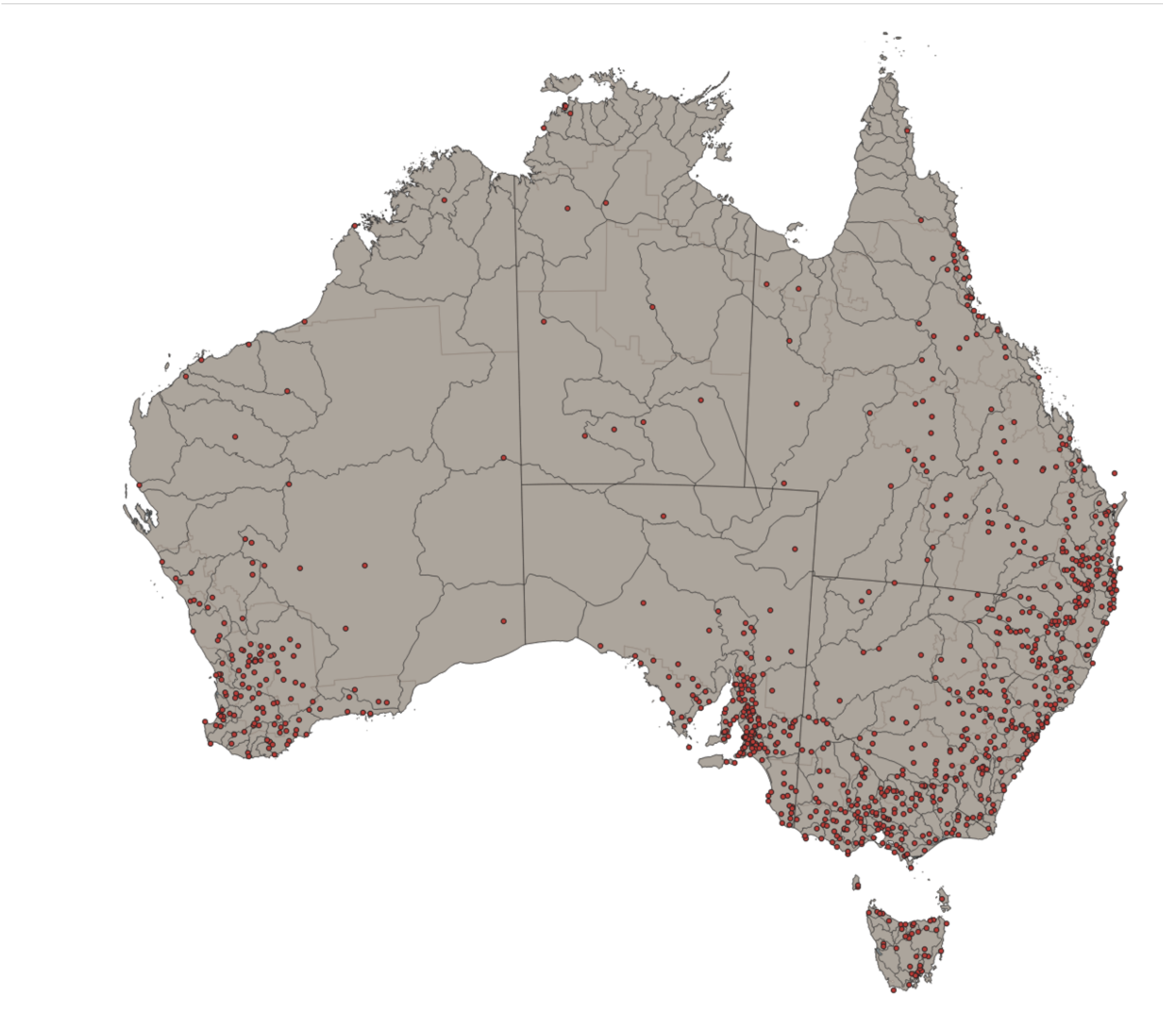
Vörösmarty, C. J., P. Green, J. Salisbury, and R. B. Lammers, 2000, Global water resources: vulnerability from climate change and population growth, *Science* 289, 284–288.

Wheeler, Sarah, Henning Bjornlund, and Adam Loch, 2014, Water trading in australia: tracing its development and impact over the past three decades, *Water Markets for the 21st Century. Global Issues in Water Policy* 11, 179–202.

Wheeler, Sarah Ann, Adam Loch, Alec Zuo, and Henning Bjornlund, 2014, Reviewing the adoption and impact of water markets in the murray–darling basin, australia, *Journal of Hydrology* 518, 28–41.

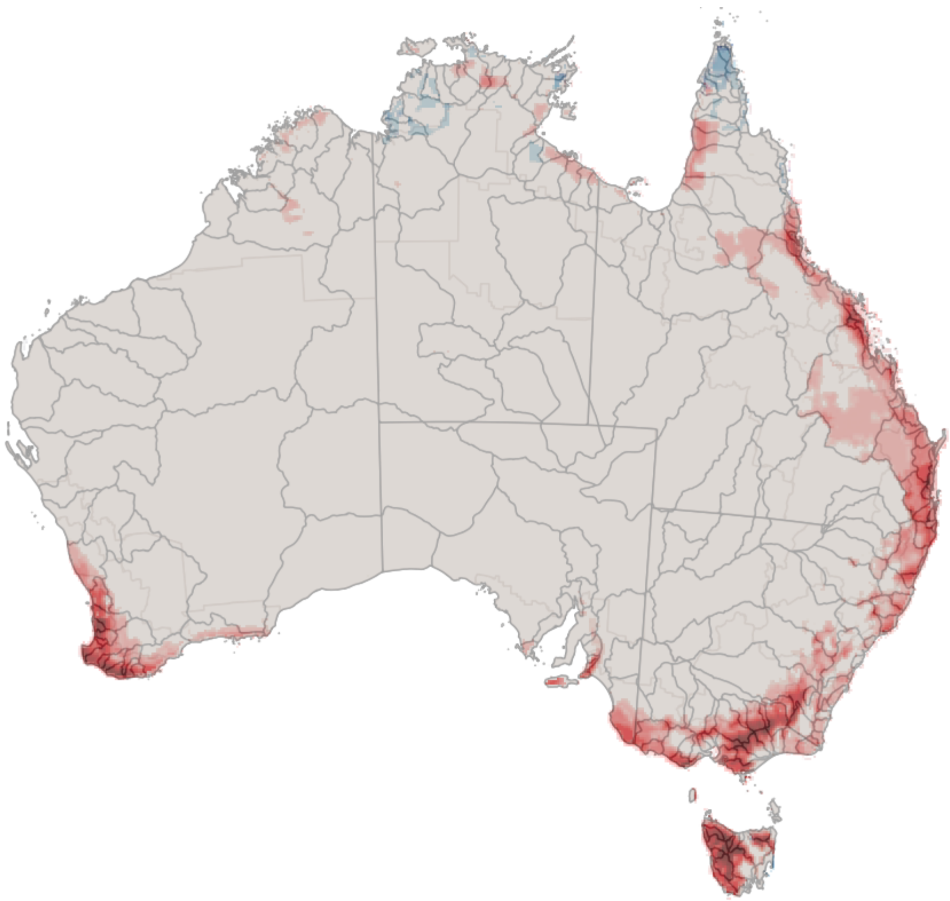
Zuo, Alec, Hong Yang, Lijin Zhong, Deli Chen, and Hao Wang, 2015, Current trends and future perspectives of water markets in china, *Journal of Cleaner Production* 92, 152–161.

Fig. 1. Australia Catchments and Weather Stations



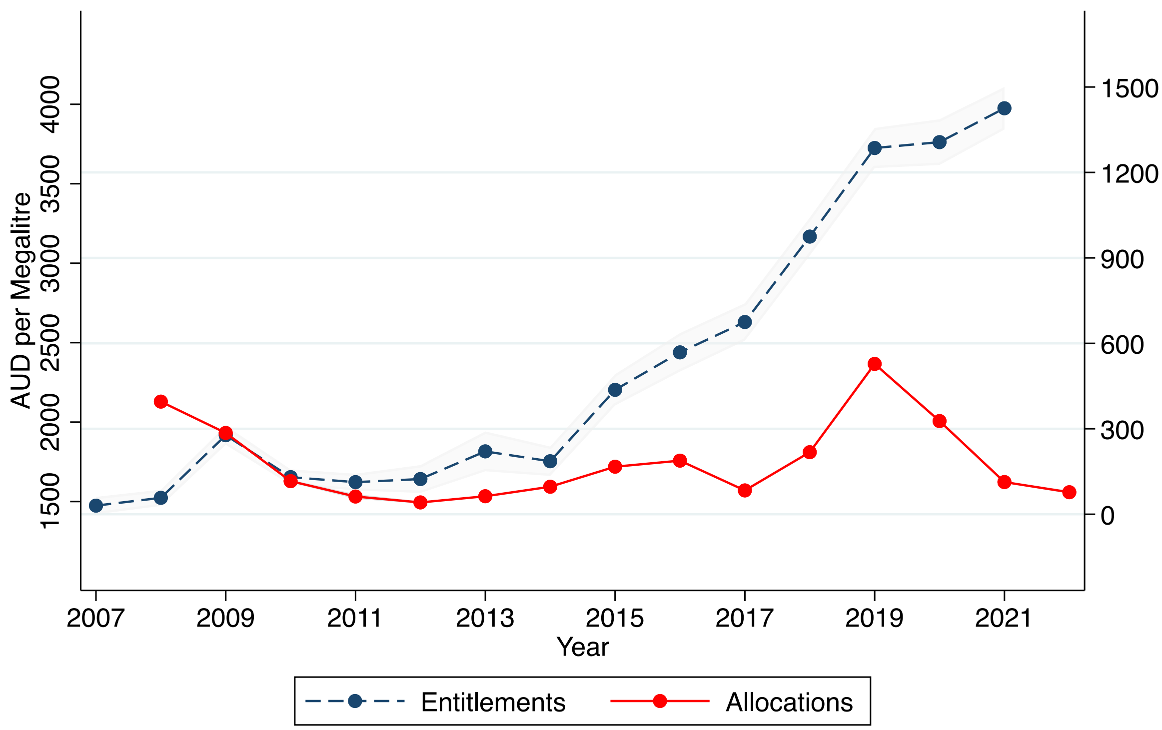
Note: This Figure presents a map of Australia divided into water catchment regions, the primary unit of economic analysis I use in this paper. Dots are weather stations which have at least 99% of months recorded with rainfall.

Fig. 2. Australia Catchments and Climate Exposure



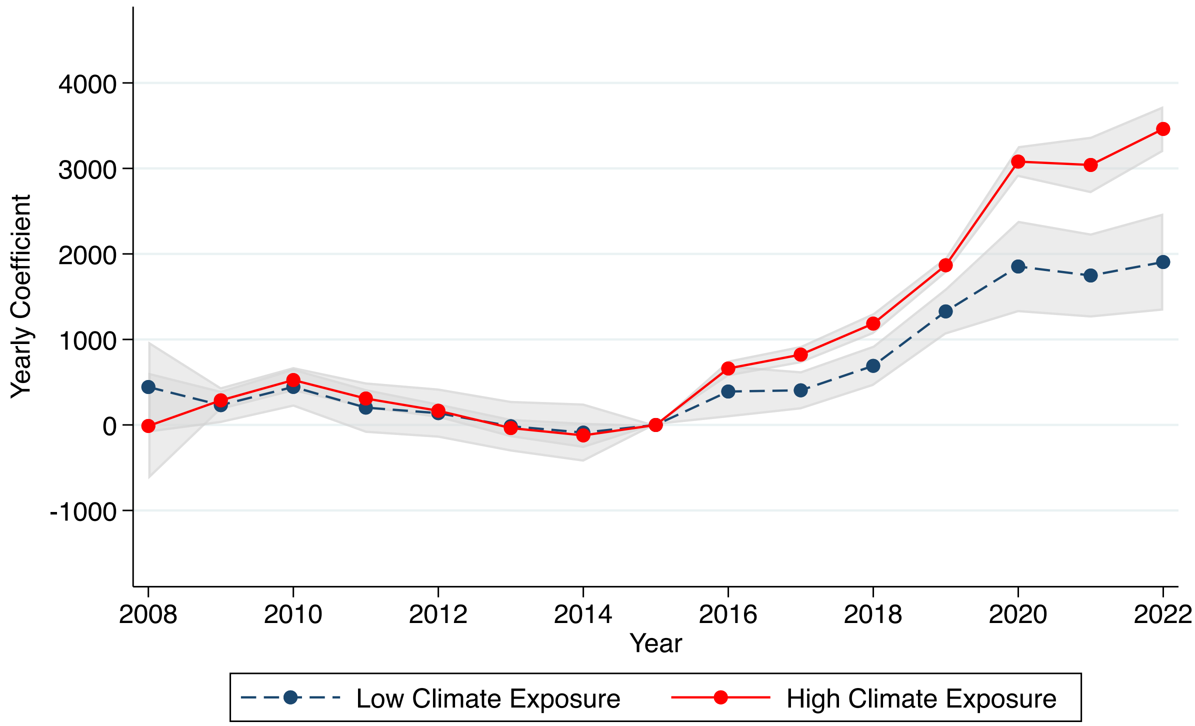
Note: This Figure presents a map of Australia divided into water catchment regions overlayed on the IPCC 2050 expected runoff changes for their median precipitation scenario.

Fig. 3. Entitlement and Allocation Prices Through Time



Note: This Figure plots prices per megalitre in the entitlement (left axis) and allocation (right axis) markets through time. Prices are calculated as median yearly price within each basin, resource type, and reliability level (entitlements), averaged across basins.

Fig. 4. Climate vs Non Climate Exposed: Entitlements

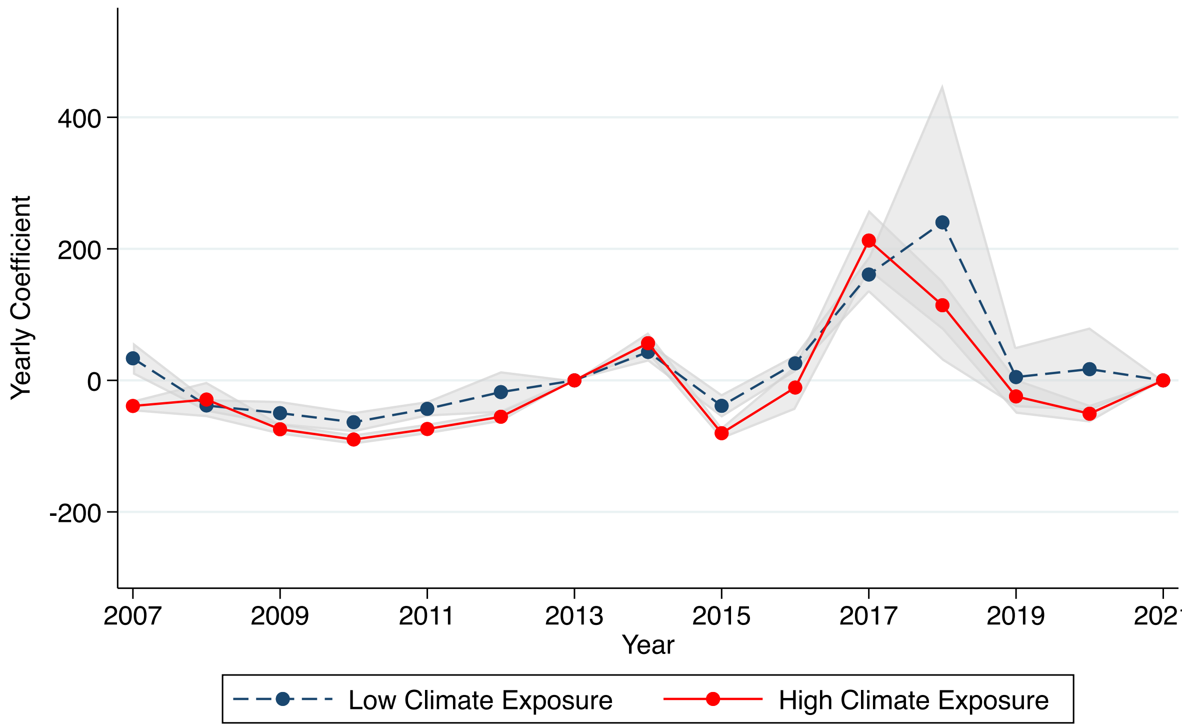


Note: This Figure plots the yearly β coefficients for climate exposed (red) and non-climate exposed (blue) areas of the following regression specification

$$p_{it} = \gamma_{rm} + \sum_{y=2007}^{2018} \beta_y \mathbf{1}_{it}^{y} + e_{it}$$

where p_{it} is the price per megalitre for the entitlement transaction, γ_{rt} represents fixed effects for the seasonal characteristics of the entitlement transaction (month x catchment x trade type x reliability x resource type). Standard errors are two way clustered by catchment and year-month.

Fig. 5. Climate vs Non Climate Exposed: Allocations



Note: This Figure plots the yearly β coefficients for climate exposed (red) and non-climate exposed (blue) areas of the following regression specification

$$p_{it} = \gamma_{rm} + \sum_{y=2007}^{2018} \beta_y \mathbf{1}_{it}^{y} + e_{it}$$

where p_{it} is the price per megalitre for the allocation transaction, γ_{rt} represents fixed effects for the seasonal characteristics of the allocation transaction (month x catchment x trade type). Standard errors are two way clustered by catchment and year-month.

Table 1. Summary Stats: Entitlement Claims

	Mean	5th Pctl	25th Pctl	Median	75th Pctl	95th Pctl	StDev	N
Price (ML)	2342.63	150	1000	1800	2525	6500	2866.46	43,809
Quantity (ML)	189.49	2	10	40	110	556	1610.02	43,809
Reliability	0.63	0	0	1	1	1	0.48	38,334
Groundwater	0.06	0	0	0	0	1	0.24	43,809
Regulated	0.90	0	1	1	1	1	0.30	43,809
Queensland	0.05	0	0	0	0	1	0.22	43,809
South Australia	0.06	0	0	0	0	1	0.24	43,809
Victoria	0.67	0	0	1	1	1	0.47	43,809
NSW	0.22	0	0	0	0	1	0.41	43,809
Other Regions	0.00	0	0	0	0	0	0.01	43,809
Pct Storage Capacity (x100)	61.95	17	43	66	84	98	25.44	43,809
Precipitation (mm)	713.66	386	515	684	829	1189	267.37	43,765
Climate Exposed								
Price (ML)	2222.80	150	1250	1899	2700	6100	1746.85	15,941
Quantity (ML)	98.07	2	5	25	85	320	577.26	15,941
Reliability	0.83	0	1	1	1	1	0.38	15,213
Groundwater	0.02	0	0	0	0	0	0.14	15,941
Regulated	0.97	1	1	1	1	1	0.17	15,941
Pct Storage Capacity (x100)	60.53	19	41	65	81	94	24.34	15,941
Precipitation (mm)	869.77	575	729	820	1002	1339	229.47	15,916
Non-Climate Exposed								
Price (ML)	2411.18	150	850	1750	2500	7160	3340.43	27,868
Quantity (ML)	241.78	2	13	50	140	780	1968.97	27,868
Reliability	0.49	0	0	0	1	1	0.50	23,121
Groundwater	0.09	0	0	0	0	1	0.28	27,868
Regulated	0.86	0	1	1	1	1	0.35	27,868
Pct Storage Capacity (x100)	62.77	17	43	66	86	98	26.01	27,868
Precipitation (mm)	624.44	370	465	565	722	1061	245.68	27,849

Note: This table displays summary stats for water rights entitlement transactions between 2007 and 2021. Trading, rainfall and water storage data are from the Bureau of Meteorology. Entitlement prices are trimmed at the 5th and 95th percentiles.

Table 2. Summary Stats: Allocation Claims

	Mean	5th Pctl	25th Pctl	Median	75th Pctl	95th Pctl	StDev	N
Price (ML)	207.59	25	75	130	290	590	236.64	185,986
Quantity (ML)	116.25	4	20	50	100	460	266.42	185,986
Groundwater	0.03	0	0	0	0	0	0.17	185,986
Regulated	0.97	1	1	1	1	1	0.17	185,986
Queensland	0.00	0	0	0	0	0	0.05	185,986
South Australia	0.06	0	0	0	0	1	0.24	185,986
Victoria	0.58	0	0	1	1	1	0.49	185,986
NSW	0.34	0	0	0	1	1	0.48	185,986
Other Regions	0.01	0	0	0	0	0	0.10	185,986
Climate Exposed								
Price (ML)	217.97	30	80	130	300	610	232.23	103,501
Quantity (ML)	91.26	3	15	41	100	300	200.37	103,501
Groundwater	0.01	0	0	0	0	0	0.11	103,501
Regulated	0.99	1	1	1	1	1	0.11	103,501
Non-Climate Exposed								
Price (ML)	190.93	20	70	125	260	540	244.15	75,763
Quantity (ML)	149.37	6	25	61	150	500	315.84	75,763
Groundwater	0.05	0	0	0	0	1	0.22	75,763
Regulated	0.95	0	1	1	1	1	0.22	75,763

Note: This table displays summary stats for one year water allocation transactions between 2008 and 2021. Trading, rainfall and water storage data are from the Bureau of Meteorology. Allocation prices are trimmed at the 5th and 95th percentiles.

Table 3. Allocations and Rainfall

Panel A: Rainfall and Allocations

	Minimum Allocation	Price (ML)	Cashflow (ML)
	(1)	(2)	(3)
Precipitation (12-month Moving Average)	0.515***	-0.379***	-0.159**
	(5.44)	(-5.30)	(-2.54)
Catchment FE	Y		
Month by Area by Trade Type FE		Y	Y
Outcome Mean	61	209	114
Outcome SD	31	239	99
Observations	236	173,950	147,410
R^2	0.2634	0.1145	0.1023
Within-R^2	0.0895	0.1023	0.0966

Panel B: Rainfall and Entitlement Prices

	(1)	(2)	(3)	(4)
Water Storage Pct Capacity (12-month MA)	-5.784***	1.945		
	(-2.83)	(0.48)		
Precipitation (12-month MA)			-6.370**	6.373
			(-2.55)	(0.87)
Price per ML Allocation		2.149**		2.375**
		(2.57)		(2.22)
Month by Area by Trade Type FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Outcome Mean	2,126	2,119	2,124	2,117
Outcome SD	1,619	1,582	1,617	1,579
Observations	38,342	34,091	38,301	34,050
R^2	0.4648	0.5014	0.4649	0.5054
Within-R^2	0.0089	0.1116	0.0086	0.1184

Note: This table presents the results from OLS regressions relating Allocation amounts and prices (Panel A) and Entitlement prices (Panel B) to rainfall. In panel A, the dependent variables are described above each column, where Minimum Allocation is the minimum cummulative distribution for a catchment in a given water year. Cashflows are defined as the minimum allocation × the price. For panel B, the dependent variable is the price per ML for entitlement claims. "Trade FEs" include fixed effects For trade level regressions, errors are two way clustered at the year-month and catchment level. Catchment level regressions are clustered by catchment.

Table 4. Climate Risk and Entitlement Prices

	(1)	(2)	(3)
Climate Exposed	-265.973		
	(-1.42)		
Climate Exposure × 1(Year 2007)	380.025***		
	(2.80)		
Climate Exposure × 1(Year 2008)	455.223**	-67.853	3.441
	(2.52)	(-0.70)	(0.07)
Climate Exposure × 1(Year 2009)	292.183**	-61.118	-15.520
	(2.45)	(-0.64)	(-0.33)
Climate Exposure × 1(Year 2010)	242.588*	46.795	116.110
	(1.70)	(0.62)	(0.76)
Climate Exposure × 1(Year 2011)	193.852	-19.545	93.392
	(1.46)	(-0.59)	(0.69)
Climate Exposure × 1(Year 2012)	45.669	-81.595	12.794
	(0.49)	(-1.06)	(0.42)
Climate Exposure × 1(Year 2013)	-110.916	12.904	-16.073
	(-1.45)	(0.30)	(-0.32)
Climate Exposure × 1(Year 2015)	393.523**	115.548	152.845
	(2.58)	(1.58)	(1.62)
Climate Exposure × 1(Year 2016)	331.112**	193.051**	262.117**
	(2.23)	(2.48)	(2.67)
Climate Exposure × 1(Year 2017)	446.894*	259.593***	286.053***
	(1.88)	(3.13)	(3.39)
Climate Exposure × 1(Year 2018)	549.503*	493.987**	493.689**
	(1.91)	(2.50)	(2.40)
Climate Exposure × 1(Year 2019)	1110.720**	1166.760***	926.286***
	(2.27)	(3.31)	(3.19)
Climate Exposure × 1(Year 2020)	1332.495**	1215.021***	1247.410***
	(2.47)	(3.28)	(4.30)
Climate Exposure × 1(Year 2021)	1715.761***	1439.231***	1427.642***
	(3.58)	(3.62)	(3.86)
Precipitation (12-month Moving Average)			-0.261
			(-1.11)
Water Storage Pct Capacity (12-month Moving Average)			554.838
			(0.67)
Price per Megalitre Allocation			0.688**
			(2.77)
Area and Trade Type FE	N	Y	Y
Year FE	Y	Y	Y
Outcome Mean	2,102	2,126	2,117
Outcome SD	1,690	1,619	1,579
Observations	43,809	38,334	34,050
R^2	0.2288	0.7507	0.7912
Within-R^2	0.0264	0.5384	0.6279

Note: This table displays the yearly coefficient estimates for climate exposed areas of the following regression specification

$$p_{it} = \alpha_y + \gamma_{rm} + \sum_{y=2007}^{2018} \beta_y \mathbf{1}^c_{it} c \mathbf{1}^y_{it} + \theta X_{it} + e_{it}$$

where p_{it} is the price per megalitre for the entitlement transaction, $1^c_{it}c$ is an indicator for whether the transaction is in a climate exposed catchment, 1^y_{it} is an indicator for whether transaction occurs in year y, γ_{rt} represents fixed effects for the seasonal characteristics of the entitlement transaction (month x catchment x trade type x reliability x resource type), α_y are year fixed effects and X_{it} is a vector of control variables for the transaction including previous year's precipitation, water storage, and the contemporaneous allocation prices. Climate exposure is defined as above median for projected runoff reduction in 2050. Standard errors are two way clustered by catchment and year-month.

Table 5. Spillovers

	(1)	(2)	(3)	(4)	(5)
Climate Exposed × Post 2014	782.252***	670.061***	719.812***	709.731***	558.824***
	(5.43)	(3.50)	(4.09)	(3.92)	(8.45)
ABARES Price (Entitlement)		0.349***		0.159	
		(4.68)		(1.54)	
ABARES Price (Allocation)			0.082	0.082	
			(0.26)	(0.27)	
Weather and Local Allocation Controls	Y	Y	Y	Y	Y
Month by Area by Trade Type FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	N
ABARES by Time FE	N	N	N	N	Y
Outcome Mean	2,086	2,086	2,012	2,012	2,103
Outcome SD	1,592	1,597	1,543	1,543	1,618
Observations	36,531	36,312	33,820	33,819	83,379
R^2	0.4755	0.4862	0.4341	0.4347	0.5320
Within-R^2	0.0351	0.0545	0.0292	0.0301	0.0149

Note: This table displays the coefficient estimates from the following regression:

$$p_{it} = \alpha_y + \gamma_{rm} + \eta_{at} + \beta \mathbf{1}^c_{it} c\mathbf{Post\ 2014}_{it} + \theta X_{it} + e_{it}$$

where p_{it} is the price per megalitre for the entitlement transaction, $1^c_{it}c$ is an indicator for whether the transaction is in a climate exposed catchment, $Post2014_{it}$ is an indicator for whether transaction occurs in year between 2015 and 2021, γ_{rt} represents fixed effects for the seasonal characteristics of the entitlement transaction (month x catchment x trade type x reliability x resource type), η_{at} is a fixed effect for the broad ABARES region by time, α_y are year fixed effects and X_{it} is a vector of control variables for the transaction including previous year's precipitation, water storage, and the contemporaneous allocation prices. Climate exposure is defined as above median for projected runoff reduction in 2050. Standard errors are two way clustered by catchment and year-month.

Table 6. Real Effects

	Crop Receipts		Profits	Water Charges
	(1)	(2)	(3)	(4)
Water Storage Level (std)	5170.094	-1218.571	-2716.900	-136.268
	(0.67)	(-0.12)	(-0.17)	(-0.96)
Water Storage Level (std) × Post 2008	20642.135	-34313.319**	-20908.554	-396.644
	(1.02)	(-2.22)	(-0.97)	(-1.64)
Centralized Market	34924.125**	32291.350***	28798.334*	1009.221**
	(2.29)	(2.93)	(1.95)	(2.45)
Centralized Market × Post 2008	77527.243**	54849.647**	19362.269	35.820
	(2.24)	(2.34)	(1.16)	(0.04)
Water Storage Level (std) × Centralized Market		9306.730	19478.850	56.028
		(0.89)	(1.19)	(0.40)
Water Storage Level (std) × Centralized Market × Post 2008		63280.190**	47920.009*	909.232**
		(2.82)	(1.95)	(2.62)
ABARES FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Outcome Mean	109,842	109,842	28,402	1,989
Outcome SD	111,366	111,366	82,139	4,147
Observations	524	524	524	524
R^2	0.8236	0.8392	0.5272	0.8185
Within-R^2	0.1283	0.2058	0.1167	0.0213

Note: This table displays the coefficient estimates from the following regression:

$$p_{it} = \alpha_y + \gamma_{rm} + \eta_{at} + \beta \mathbf{1}^c_{it} c \textbf{Post 2014}_{it} + \theta X_{it} + e_{it}$$

where p_{it} is the price per megalitre for the entitlement transaction, $1^c_{it}c$ is an indicator for whether the transaction is in a climate exposed catchment, $Post2014_{it}$ is an indicator for whether transaction occurs in year between 2015 and 2021, γ_{rt} represents fixed effects for the seasonal characteristics of the entitlement transaction (month x catchment x trade type x reliability x resource type), η_{at} is a fixed effect for the broad ABARES region by time, α_y are year fixed effects and X_{it} is a vector of control variables for the transaction including previous year's precipitation, water storage, and the contemporaneous allocation prices. Climate exposure is defined as above median for projected runoff reduction in 2050. Standard errors are two way clustered by catchment and year-month.