Estimating the insurance value of ecosystem resilience:

Evidence from the Australian Goulburn-Broken Catchment

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Abstract: We estimate the economic insurance value of ecosystem resilience for the Goulburn-Broken Catchment farmland in South-East Australia, which is threatened by salinization due to rising groundwater tables. We find that although the system is close to a regime shift, ecosystem resilience provides a sizeable economic insurance value. With a baseline estimation of 1.4 million 1991 Australian Dollars, this is an additional value component of resilience amounting to a third of the expected value of resilience that Walker et al. (2010) have estimated previously. We also analyse the time profile of the insurance value. This suggests that while the overall net present insurance value is substantial, monthly insurance values towards the end of the time horizon are negative due to a higher flip probability and thus call for complementary financial insurance.

JEL-Classification: G22, Q15, Q24, Q57

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1 Introduction

This paper is concerned with the estimation of the economic insurance value of ecosystem resilience. We provide empirical evidence for a case study from the Goulburn-Broken Catchment farmland in South-East Australia, whose resilience is threatened by salinization due to rising groundwater tables.

An ecosystem's *resilience* is its ability to maintain its basic functions and controls while undergoing change and experiencing shocks (Holling 1973, Pimm 1984, Grimm and Wissel 1997), also defined, for example by Walker et al. (2004), as the "capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks".[1] A resilience approach to the analysis and management of ecosystems draws attention to non-linear system dynamics and to tipping points in the provision of ecosystem services between multiple stability domains or 'regimes', occurring on various temporal and spatial scales (Folke et al. 2004; Scheffer et al. 1993, 2001; Lenton et al. 2008; Rockström et al. 2009). The existence of multiple regimes and corresponding thresholds is supported by empirical evidence for a growing number of systems (Resilience Alliance and SFI 2004, Walker and Meyers 2004).

Without a resilient provision of important ecosystem services, human life on Earth would not be possible (Arrow et al. 1995). For devising efficient ecosystem management strategies, the natural insurance ecosystems provide must be accounted for. Since resilience of life-supporting (eco-)systems is of key importance for a sustainable development, as a possible irreversible shift in ecosystem service provision may have devastating effects, scholars (Brock et al. 2002; Täler 2008; Perrings 2006) have pondered over how to account for it in order to devise efficient policies and to guarantee a sufficient investment in resilience. Resilience has often been interpreted as insurance, as a higher level of resilience reduces the probability of the occurrence of an unwelcome regime shift (i.e. crossing a threshold). Baumgärtner and Strunz (2014), however, have shown that only a part of resilience' function actually serves as an insurance in its economic sense. Such a standard definition of economic insurance commonly includes three components: (i) objective risk characteristics, i.e. different states of nature that may occur with certain probabilities, (ii) subjective risk preferences of the

[1] Alternative conceptions of resilience, such as 'engineering resilience' after Pimm (1984, 1991), are concerned with the speed with which a system returns to its equilibrium state following a perturbation, or have broadened the focus to social-ecological systems (for an overview, see Brand and Jax 2007).

decision maker, and (iii) a mechanism that allows for a mitigation of the perceived risk. Baumgärtner and Strunz (2014) adopt the classic insurance definition of McCall (1987), whereby insurance is an institution that mitigates the influence of uncertainty on a person's well-being. Accordingly, the insurance value of ecosystem resilience can be defined as the function of a resilience stock to reduce an ecosystem user's (income) risk from using ecosystem services, whose provision may be subject to regime shifts. Determining the insurance value of resilience is important for knowing whether resilience actually functions as an insurance and for deciding on whether one should insure oneself via providing real actions to increase resilience or by buying substitutive financial insurance contracts.

The aim of this paper is therefore to estimate the economic insurance value of resilience for the most prominent economic resilience assessment so far: the Goulburn-Broken Catchment (GBC) case study from South East Australia presented in Walker et al. (2010). The GBC is a highly productive agricultural region that is threatened by salinization due to rising groundwater tables – a danger many farmers face all around the world (Walker and Pearson 2007). Walker et al. (2010) have shown, using a capital-pricing theoretic resilience evaluation, that the expected value of resilience is sizeable and amounts to 4.5 million Australian Dollars for the GBC case study. To estimate the insurance value of ecosystem resilience, we combine the modelling frameworks of Walker et al. (2010) and Baumgärtner and Strunz (2014), provide an estimate of the insurance value for the GBC case study, and discuss the potential for further economic evaluation of ecosystem resilience. We find that although the system comes very close to a regime shift towards the end of the time horizon, ecosystem resilience provides a sizeable economic insurance value. With a baseline estimation of 1.4 million Australian Dollars, this is an additional value component of resilience amounting roughly to a third of the expected value of resilience that Walker et al. (2010) have estimated previously. We also analyse the time profile of the insurance value. This suggests that while the overall net present insurance value is substantial, monthly insurance values towards the end of the time horizon are negative due to a higher flip probability and thus call for complementary financial insurance.

The paper is structured as follows. Section 2 provides a description of the resilience dynamics in the GBC. In Section 3, we present our modelling framework and definitions. Section 4 present the data and Section 5 reports the results of estimating the economic insurance value of resilience. Section 6 discusses the results, while Section 7 concludes.

2 Case study: Water table dynamics in the Goulburn-Broken Catchment, Australia

The Goulburn-Broken Catchment (GBC) is located in South East Australia in the State of Victoria, covering 2.1 million hectares (Figure 1).[2] It is one of Australia's most important

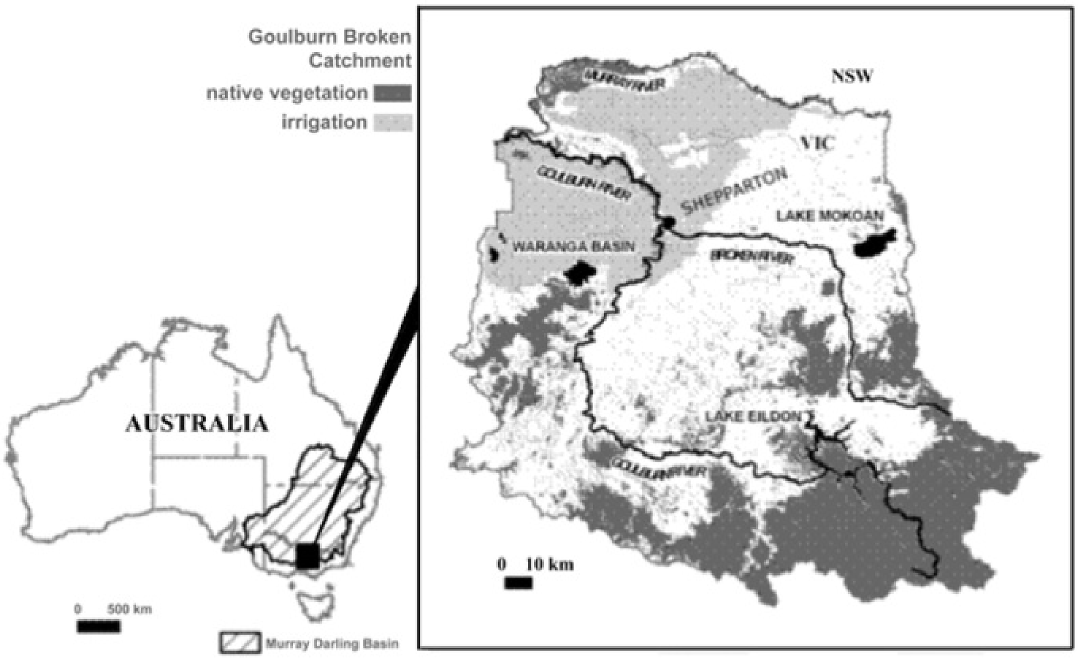

Figure 1: Functional map of the Goulburn-Broken Catchment (from Walker et al. 2009) including the later analysed irrigation area.

agricultural regions, with the dairy processing sector being the largest contributor to the region's marketed output. Most of the agricultural production takes place in the lower (to the sea level) parts of the GBC – an area of 300,000 ha that is only covered by 2% of native vegetation and is predominantly used for irrigated dairy (80%) as well as fruit production. In addition to marketed output, non-marketed goods such as ecosystem services constitute a substantial part of regional welfare.

[2]Our description of the GBC is based on Walker and Salt (2006), Walker et al. (2009) and Walker et al. (2010), who have studied this system in the context of ecological-economic resilience.

Walker et al. (2009) provide an extensive assessment of resilience in the GBC region. First, they identify major problems in the region – such as rising saline water tables threatening crop production or insufficient native dryland vegetation connectivity leading to biodiversity loss – and discuss specified and general resilience in this setting.[3] A fundamental attribute of ecological systems is their complexity. It may thus be difficult to meaningfully define the state of an ecosystem and changes in it, as the system will be described by an abundance of factors. Different instances of specified resilience are presented, grouped into the three subsystems of the social-ecological-economic system. For every instance, Walker et al. (2009) also provide a three-step assessment of the degree of uncertainty in the knowledge of the specific threshold (known, strongly suspected and unknown).

In their resilience evaluation of the GBC, Walker et al. (2010) have included three instances of specified resilience: (i) rising groundwater tables leading to a salinization of the soils, (ii) native dryland vegetation connectivity determining nature conservation, and (iii) the condition of the irrigation infrastructure. However, only the first instance is analyzed in detail by Walker et al. (2010). We therefore also focus on this instance as well.

According to Walker and Salt (2006), the groundwater table was between 20 and 50 meters below the surface before European settlers arrived and occupied the land of the Aboriginal people. To create space for the new settlements and, in particular, for cultivation and agricultural production, natural vegetation has been largely cleared. Together with the later installed irrigation infrastructure, this has led to a successive rise of the water table. Because of salt deposits in the soil profile, a rising water table constitutes a major threat to the productivity of the soil, as the salinized water will be drawn to the surface by capillary action if it reaches a critical threshold of approximately 2 meters below the surface (Walker et al. 2010). Half of the GBC irrigation region is now threatened by salinization. As a response to the past crossing of the critical threshold in the 1950es and 1970es, which led to widespread crop losses, pumps have been installed that are supposed to keep the water level below 2 meters under the soil.

Thus, the GBC is in a situation where the threshold to a new equilibrium with salinized

[3]Resilience researcher differentiate between specified resilience, with which we deal in this paper, and general resilience (Carpenter et al. 2001). A general resilience perspective (see also Walker and Salt 2006) approaches complexity without trying to simplify systems for model building and emphasizes the importance of modularity, i.e. the loose connectedness between different components of a system, and diversity, in particular functional and response diversity.

soils may have already been crossed, with only the installed pumping machinery keeping it in the desired high productivity regime (Walker and Salt 2006). Figure 2 illustrates these resilience dynamics. It explains soil fertility with the depth of the water table relative to

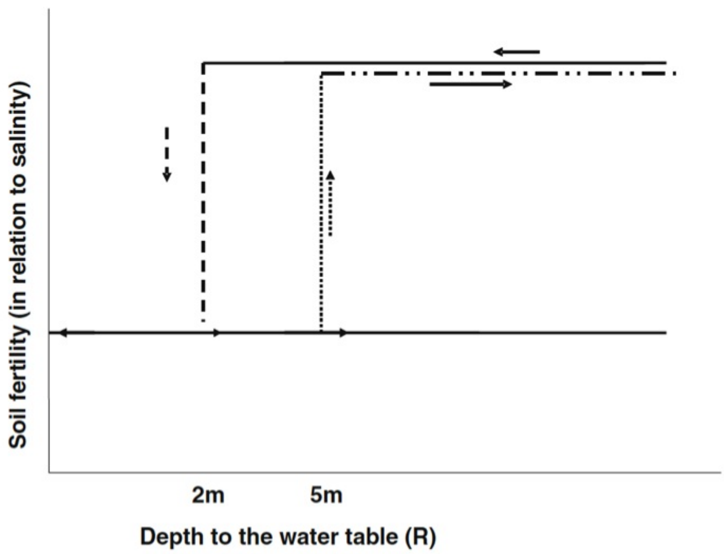

Figure 2: Bifurcation diagram for the relationship between soil fertility and water table depth (from Walker et al. 2010).

the topsoil, also exhibiting a hysteresis effect. Over time, the water table may rise due to higher irrigation input or rain fall but the system remains in the high-soil-fertility regime (solid line). If further inputs occur and pumping cannot reduce the water table, it may cross the critical threshold at 2 meters below the surface, thus leading to a salinized soil; the land will loose its productivity almost entirely.[4] For a small decadal scale, this regime shift can be regarded as irreversible, but the high productivity soil may be revitalized if the salt is flushed away and tree planting and increased pumping activity can insure that the water table is sufficiently distant from the critical threshold. In Figure 2, this threshold is at a water table 5 meters below the surface.

[4]The two major land management regimes – horticultural and dairy production – are affected differently by a possible salinization, as horticultural crops are more sensitive to salinity (due to their longer roots) as pastures (Walker et al. 2010; see also Section 4).

3 Model description and definitions

Our model combines elements from two sources: first, the model of Walker et al. (2010) that describes the resilience dynamics in the Goulburn-Broken Catchment; second, the model of Baumgärtner and Strunz (2014), who conceptualize the economic insurance value of ecosystem resilience for a risk-averse user of ecosystem services. Thereby, the insurance value of ecosystem resilience is the function of a resilience stock to reduce an ecosystem user's (income) risk from using ecosystem services, whose provision may be subject to regime shifts.

Our model considers an ecological-economic system with two regimes, where the initial regime is characterised by a high level of ecosystem service provision and corresponding high income and the alternate regime with salinized soil is associated with a low level of ecosystem service provision and a low income. Following Walker et al. (2010), we define resilience as a stock variable R_t at time t that equals the distance from the current water table to the threshold level of 2 meters under ground and that depends on the initial resilience stock R_0.[5]

If the water-table threshold is breached, the system changes irreversibly from the initial, productive regime to the salinized regime. The probability distribution of a regime shift in time t for an initial resilience stock R_0 (also referred to as 'flip probability' in the following) is denoted by $f(R_t(R_0))$. The corresponding cumulative flip probability up to time t is given by $F(R_t(R_0), t)$. Note that we omit the indirect dependence of $F(\cdot)$ on R_t in the following, as R_t is fully determined by the initial resilience level R_0 and the forecasted linear development path of R_t over time. Accordingly, the cumulative probability that the system has not flipped until time t, i.e. the 'survival probability', is given by $S(R_0, t) = 1-F(R_0, t)$, which we specify based on Walker et al. (2010) as

$$S(R_0, t) = \prod_{\tau=1}^{t} \left(1 - \theta e^{-\eta R_\tau(R_0)}\right), \tag{1}$$

where p is the time horizon, θ a benchmark probability for a flip if the initial resilience stock would be zero and η a parameter measuring how fast the flip probability decreases as the

[5]Walker et al. (2010: 195) state that R_t depends on R_0 "according to a certain stochastic process", which may refer to the previous work of Mäler et al. (2007: 11f.), who specify such a stochastic process. Yet, they further assume that the forecasted development of the resilience stock R_t over time is governed by a *linear* process (Walker et al. 2010: 194).

resilience stock increases. The survival probability increases with an increasing resilience level and is, ceteris paribus, lower for longer time horizons.

According to this model set-up, the representative farmer faces a binary current value income lottery that only varies with the initial level of resilience R_0 for a given time horizon T.[6] It is further assumed that income is only a part of the farmer's total wealth. A period's current value income in the productive regime is denoted as y, which is assumed to be constant. In case of a regime shift into the salinized regime, the farmer incurs an income loss of Δy and the current value income in the salinized regimes is thus denoted as $y - \Delta y > 0$. In a given period t, the farmer thus faces the following binary current value income lottery (R_0, t): $\{y,\, y - \Delta y;\; F(R_0;t), (1 - F(R_0;t))\}$, where $F(R_0;t)$ denotes the cumulative probability distribution of a regime shift up to period t for an initial resilience stock R_0.

We assume that the farmer's preferences over the current value income lottery (R_0, t) are described by a von Neumann-Morgenstern expected utility function

$$U = E_{R_0;t}[u(y)] \quad \text{with} \quad u'(y) > 0 \text{ and } u''(y) < 0 \text{ for all } y, \tag{2}$$

where $E_{R_0;t}$ is the expectancy operator based on the probabilities of the income lottery (R_0, t), y is current value income, here given as a random variable that has the two realisations y and $y - \Delta y$, and $u(y)$ is a continuous and differentiable Bernoulli utility function, assumed to be increasing and strictly concave. We further assume that farmers are risk-averse with constant relative risk aversion (CRRA), which has been found to be a suitable description of the risk preference of Australian farmers (Kingwell 1994):

$$u(y) = \frac{1}{1-\rho} y^{1-\rho}, \qquad \text{with} \quad \rho \geq 0, \quad \rho \neq 1; \tag{3}$$

where the coefficient of CRRA ρ measures the degree of risk aversion.

The riskiness of the income lottery (R_0, t) in period t is captured by its current value risk premium $\Pi(R_0;t)$, depending on the initial resilience stock and time t, that is the

[6] Following Walker et al. (2010: 189), resilience at the farm level is specified as the "resilience of crop production in the [GBC] to variations in the [ground-]water table" for a 40-year time horizon. Walker et al. (2010), however, have not analysed single specific farms but provided an estimate of the economic value of resilience for the whole system, implicitly assuming that the water table dynamics are similar on all farms. Since it is beyond the scope of this study to analyse the insurance value of resilience for all heterogeneous farmers in the GBC, it will be assumed that all individual farmers are assumed to be identical.

(maximum) amount of money that the farmer would be willing to pay at time t to receive the expected income for sure instead of having to play the risky lottery:

$$u(E_{R_0;t}[y] - \Pi(R_0;t)) = E_{R_0;t}[u(y)]. \tag{4}$$

With CRRA utility, the risk premium is given by (cf. Appendix B):

$$\Pi(R_0;t) = E_{R_0;t}[y] - \left(E_{R_0;t}[y^{1-\rho}]\right)^{\frac{1}{1-\rho}}. \tag{5}$$

The *economic insurance value* of ecosystem resilience in period t in current value terms is then defined as the change of the risk premium Π of the income lottery (R_0, t) at time t due to a marginal change in the initial level of resilience R_0:

$$I(R_0;t) := -\frac{d\Pi(R_0;t)}{dR_0}. \tag{6}$$

To be able to compare our results of introducing risk aversion to the model as closely as possible to the findings of Walker et al. (2010) who have calculated the expected value of resilience, we follow their assumption that the curvature of the utility function for intertemporal consumption smoothing is linear and assume exponential discounting with a discount rate denoted δ. We can now state our main proposition:

Proposition 1

The intertemporal, *economic insurance value of resilience* in net present value terms $I_{NPV}(R_0;T)$ is given by the simple discounted sum of all single period's present value insurance values up to time horizon T:

$$I_{NPV}(R_0;T) := \sum_{\tau=1}^{T} \frac{1}{(1+\delta)^\tau} I(R_0;p) \overset{\text{with CRRA}}{=} \sum_{\tau=1}^{T} \frac{1}{(1+\delta)^\tau} F'(R_0;t) \times \left\{ \Delta y - \frac{1}{1-\rho} (\Delta y)^{1-\rho} \left[F(R_0;t)(y-\Delta y)^{1-\rho} + (1-F(R_0;t)) y^{1-\rho} \right]^{\frac{\rho}{1-\rho}} \right\}. \tag{7}$$

Proof. See Appendix B. □

As demonstrated by Baumgärtner and Strunz (2014) for a constant absolute risk aversion utility (CARA) specification, the economic insurance value is only one component of the *total economic value of resilience* (V), which is defined as the maximum willingness to pay W for a marginal increase of the initial level of resilience R_0 for time t:

$$V(R_0;t) := \lim_{dR_0 \to 0} \frac{W(dR_0;t)}{dR_0} \geq 0, \tag{8}$$

where the maximum willingness to pay W is defined through

$$E_{R_0;t}[u(y)] = E_{R_0+dR_0;t}[u(y - W(dR_0;t))]. \tag{9}$$

The other component of the total economic value of resilience is given by the expected value EV of resilience. Indeed, this is the only value of resilience to a risk-neutral farmer and constitutes what Walker et al. (2010) have already calculated for the GBC case study. Formally, the expected value EV in net present value terms for increasing the initial level of resilience R_0 by a marginal unit for time t is given by

$$EV(R_0;t) := \sum_{\tau=1}^{t} \frac{1}{(1+\delta)^\tau} \left(\frac{-dF(R_0;\tau)}{dR_0} \times \Delta y \right). \tag{10}$$

The insurance value of resilience is thus only one component of its total economics value. This reflects the fact that an increase in resilience has two effects: First, it will raise expected income and, second, it may raise or lower the (perceived) riskiness of income. While in the case of CARA, the total economic value of resilience is a simple additive combination of these two effects, they cannot be algebraically disentangled for the CRRA specification used here.

4 Data

To fix the model parameters, we use the following data for the risk preferences of Australian farmers, the flip probability and net present incomes associated with the two regimes.

Risk aversion

The degree and type of risk aversion of farmers in the GBC is a key input to our model analysis. Since there are – to our knowledge – no studies on risk preferences in the GBC itself, we have surveyed the relevant related literature on the type and degree of risk aversion among Australian farmers.

Bond and Wonder (1980) conduct a survey of 201 farmers throughout Australia and find that these are mostly risk-averse. Due to shortcomings in the interview process, only tentative conclusions can be drawn from this study. Bardsley and Harris (1987) find Australian broadacre farmers to be risk averse and estimate a partial coefficient of risk aversion that decreases with wealth and increases with income and ranges from 0.072 to 0.696. Quiggin

(1981) estimate a coefficient of absolute risk aversion, roughly similar to Bond and Wonder's (1980) estimate in size (i.e. very small) but also only of an indicative nature as only a very small number of farmers have been interviewed. Abadi Ghadim et al. (2005) examine risk attitude of 114 West-Australian chickpea farmers and estimate a CARA-coefficient of 0.000055. Kingwell (1994) builds a model to describe dryland farming in Western Australia and assumes CARA risk aversion in the range of 0.000003 to 0.000005, where the 0.000003 CARA measure re-expressed as a coefficient of relative risk aversion (CRRA) is equal to 0.78 (ibid.). Kingwell (1994) further argues that a CRRA specification may be more suitable.

Besides allowing the conclusion that Australian farmers can be assumed to be risk averse, the empirical evidence on risk preferences is rather sparse and partly outdated, while many studies are of a rather indicative nature. In lack of better evidence, we employ a CRRA coefficient of 0.78 (Kingwell 1994) in the further estimation procedure and perform a sensitivity analysis with respect to this coefficient. This is also close to other more recent empirical evidence observed for commercial farmers operating under high environmental risk (see Olbricht et al. (2012) for an overview).

Income loss due to a regime shift

For the current value income data, we rely on the monthly-equivalent loss Δy caused by a flip from the productive to salinized soil calculated by Walker et al. (2010: 196) on the basis of land prices: (0.04/12) × (0.90 × 192,000 [ha] × [$/ha] 448.29 + 0.99 × 19,200 [ha] × [$/ha] 723.00) = $\$304,024.32$. This calculation has four ingredients: First, yearly land prices per hectare are estimated to be $448.29 for dairy- and $723.00 for horticultural land in the initial high production regime for the year 1991 and assumed to be constant for the analysis.[7] Second, these values are assumed to diminish by 90% (99%) in the case of dairy (horticultural) land if the system flips to the alternate, salinized regime. Third, the quantity of land threatened by salinisation is 192,000 (19,200) ha of dairy (horticultural) land. Finally, the monthly discount rate of $\delta = 0.04/12$ is used to convert yearly land prices on to a monthly basis. Accordingly, the current value monthly income in the productive regime y is $333,177.60, and the current value income the salinized regime $y - \Delta y$ $29,153.28.

[7] Although Walker et al. (2010) report that land prices have decreased until 2001, we follow their analysis of assuming constant prices to ensure comparability of results.

Water table dynamics and flip probability

The groundwater table in the GBC has decreased from 3m in 1991 to approximately 3.5m in 2001, i.e. the resilience stock has increased by 0.5m. We rely on the *normal* forecast presented in Walker et al. (2010), which predicts that the groundwater table will (linearly) rise again to 3m below the surface in 2030, making a flip to the salinized regime more likely.[8] It is further assumed that the changes in climate conditions that lead to variations in the water table do not alter other conditions of the system, which need to stay constant in this ceteris paribus analysis. It should also be noted that these forecasts only rely on projections based on historical developments and do not take future projected changes e.g. due to anthropogenic climatic change into account. The central parameters θ and η of the cumulative survival probability (Equation 1, depicted in Fig. 3) were estimated from monthly observations to be 0.4583 and 2.75 respectively, and assumed to be stable for the time horizon of the analysis (Walker et al. 2010). These past observations have only been collected from the bore of one central site and thus carry with them the assumption that water table dynamics are identical across the whole GBC (T. Baynes, personal communication, 2011).

With this specification of the survival probability function and a linear development path of the resilience stock, Walker et al. (2010) calculate the cumulative survival probability for each month, as is depicted in Fig. 3 for the *normal* climate forecast. With the provided data, we could replicate the central estimate of the expected value of resilience of Walker et al. (2010) with an accuracy of 99.92% of the $4,570,530 (in 1991 Australian Dollar) reported in Walker et al. (2010). Our estimate of the the expected value of resilience for a 1dm increase in the initial level of resilience in the initial month of the year 1991 for a time horizon of 480 month is $4,566,640.

5 Results

This section present the estimation results of the economic insurance value of resilience for the Goulburn-Broken Catchment. First, we estimate the monthly economic insurance value of ecosystem resilience in current value terms $I(R_0; t)$, defined as the change of the

[8] Walker et al. (2010) also define a *dry* forecast predicts that the water table will fall to 5m below the surface. However, as we could not obtain the corresponding data, we base our estimation solely on the *normal* climate forecast.

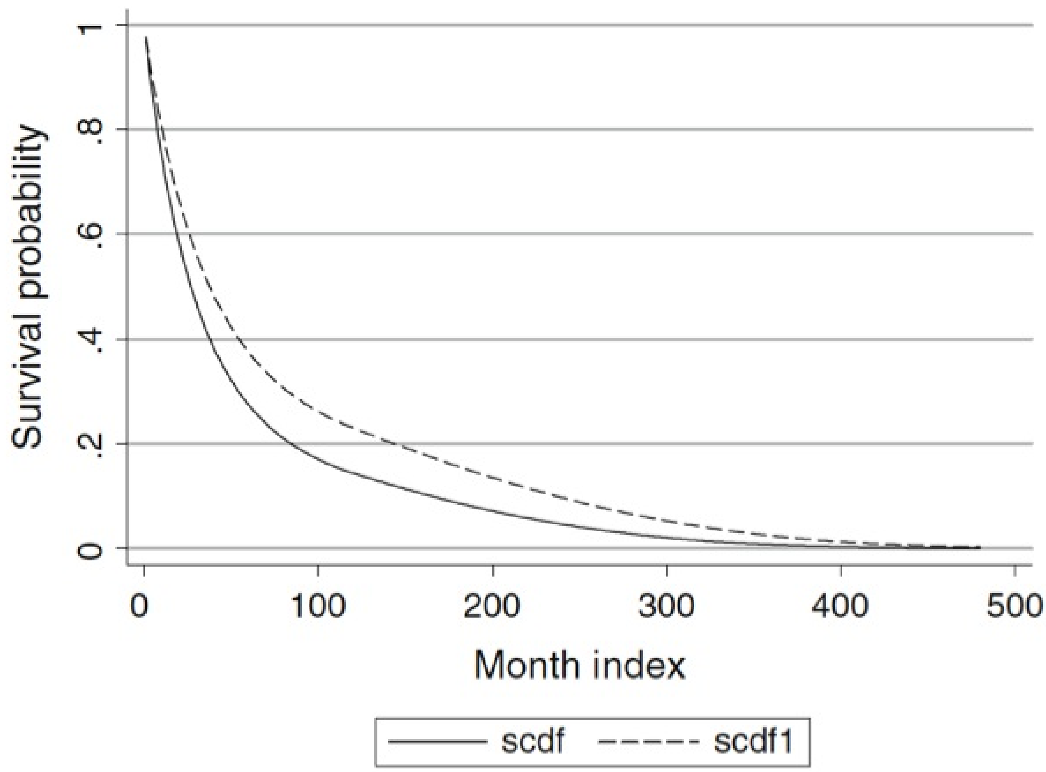

Figure 3: This Figure (taken from Walker et al. 2010) shows the cumulative survival probability $S(R_0, t)$ (cf. Equation 1) curves for all times up to $T = 480$ for different initial resilience levels of $R_0 = 10dm$ (scdf) and $R_0 + \Delta R = 11dm$ (scdf1); For each month, the vertical difference between the two curves is $\Delta S(R_0, t)$.

risk premium Π of the income lottery (R_0, t) at time t due to a marginal change in the initial level of resilience R_0. With CRRA utility, we can specify Equation 6 as follows:

$$I(R_0; t) = dF(R_0; t) \times \left\{ \Delta y - \frac{1}{1-\rho} (\Delta y)^{1-\rho} \left[F(R_0; t)(y - \Delta y)^{1-\rho} + (1 - F(R_0; t)) y^{1-\rho} \right]^{\frac{\rho}{1-\rho}} \right\}. \quad (11)$$

We illustrate the development of $I(R_0; t)$ over the time horizon in Figure 4. We find that the monthly insurance value has a maximum amount of \$37,801 (in 1991 AUS Dollars) in month 13 and becomes negative from month 133 onwards driven by the decreasing resilience stock from month 120 onwards reflected in an increasing monthly flip probability.

With the use of the monthly discount rate of $\delta = 0.04/12$ we can now compute the economic insurance value of resilience in net present value terms $I_{NPV}(R_0; T)$ (cf. Equa-

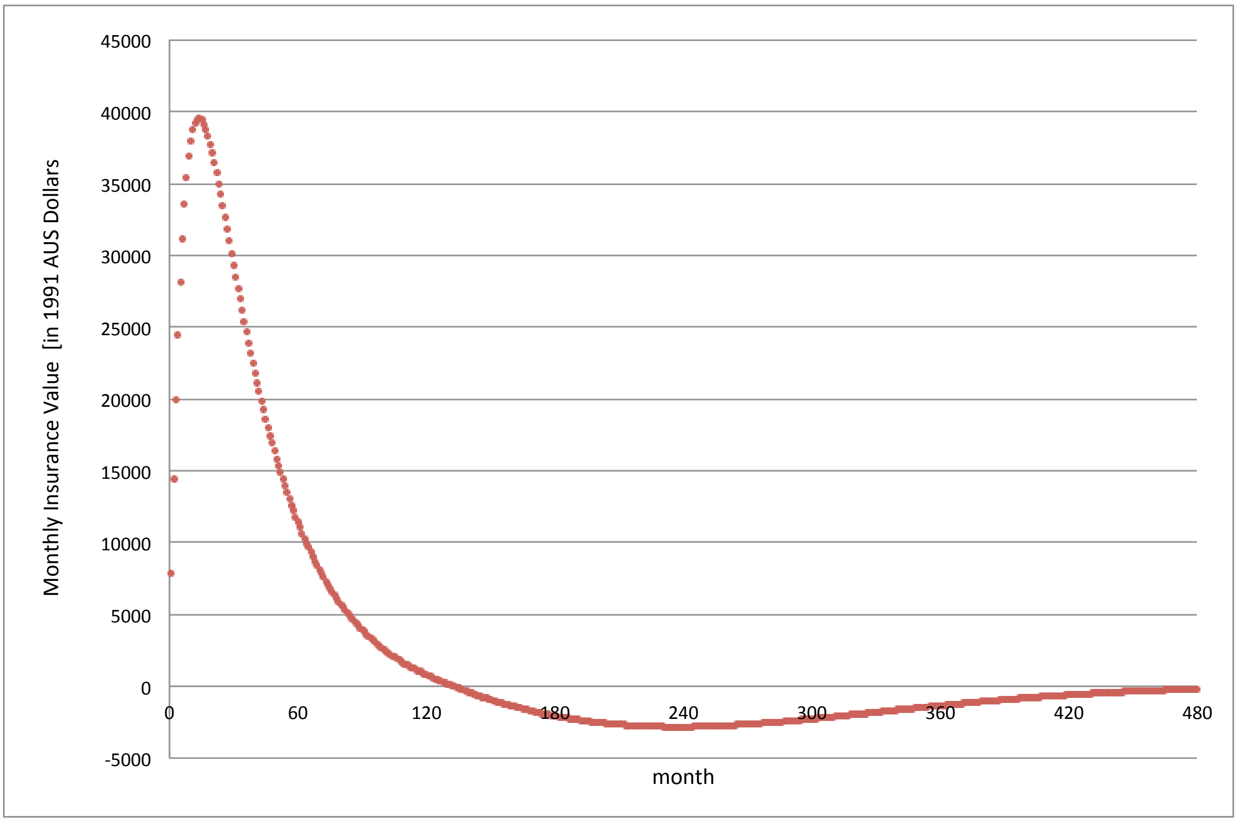

Figure 4: Monthly economic insurance value of resilience $I(R_0;t)$ in current value terms (cf. Equations 6 and 11) and for the baseline scenario of a coefficient of constant relative risk aversion of 0.78 and a yearly discount rate of 4% in 1991 AUS Dollars.

tion 7) in the year 1991 for a representative farmer in the Goulburn-Broken Catchment. We illustrate the time development of $I_{NPV}(R_0;T)$ in Figure 5 and find that for a 40-year time horizon the economic insurance value of resilience amounts to 1,409,202$in 1991 prices.

The other component of the total economic value of resilience is given by the expected value of resilience $EV(R_0;t)$ (cf. Equation 10), as previously estimated by Walker et al. (2010) for the GBC case study. Our approximation of the expected value of resilience based on the data of Walker et al. (2010) yields a value of 4,566,640$. The economic insurance value of resilience thus additionally yields a value that is 31% of the size of the expected value and thus constitutes a previously overlooked but sizeable value component.

As the degree of risk aversion, here in the form of the CRRA-coefficient ρ, is the most important novel input to the estimation model and its actual magnitude for the farmers in the GBC could only be approximated from the risk aversion exhibited by comparable

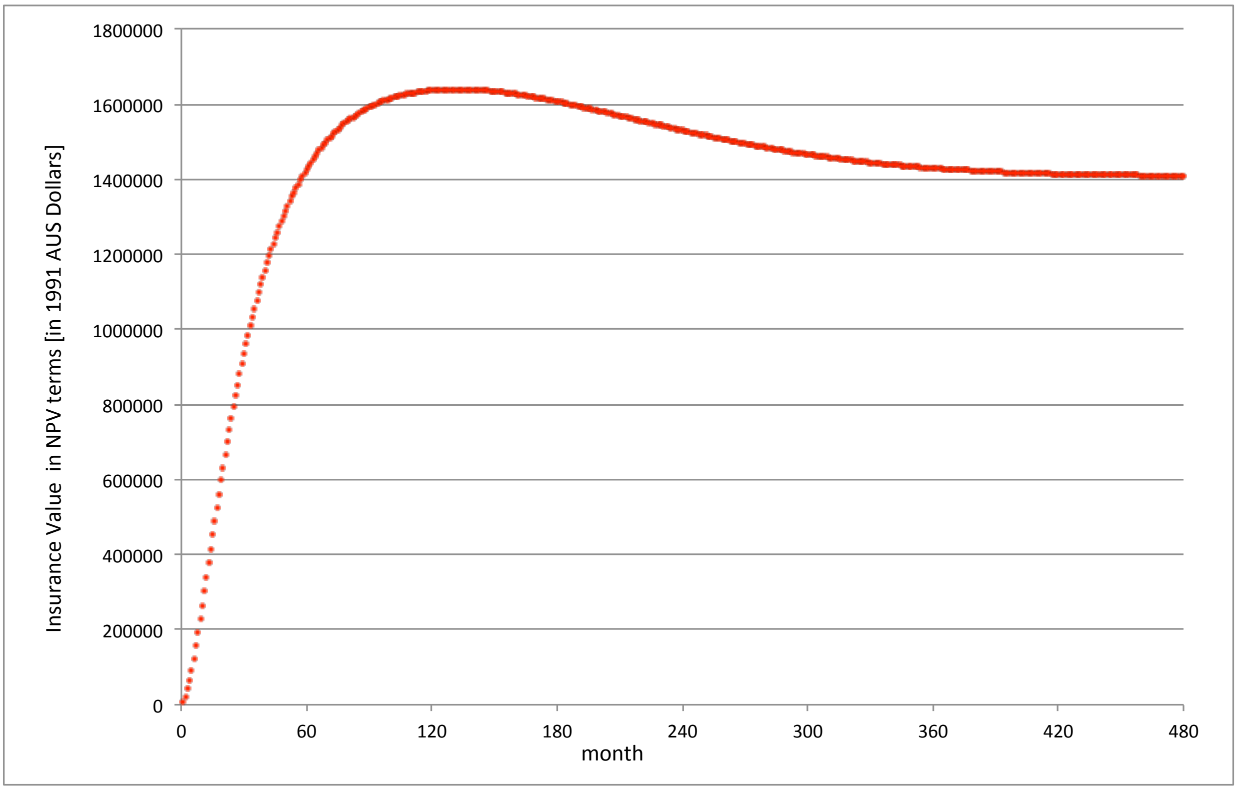

Figure 5: Economic insurance value of resilience in net present value terms $I_{NPV}(R_0; T)$ (cf. Equation 7) for the baseline scenario of a coefficient of constant relative risk aversion of 0.78 and a yearly discount rate of 4%.

farmers, a sensitivity analysis of the insurance value of resilience with respect to the CRRA-coefficient is conducted. We present this sensitivity analysis in Fig. 6.

The analysis shows that the value of the economic insurance value of resilience is indeed highly sensitive to the degree of constant relative risk aversion. Specifically, as an increase in the initially assumed value of 0.78 by 1% leads to an increase in the insurance value of 9% and a not unreasonable increase in ρ of up to a value of 0.9 increases the size of the insurance value by more than 300% to a value of 5,877,838$, which is already higher than the expected value of resilience estimated by Walker et al. (2010). On the other hand, decreasing the coefficient of constant relative risk aversion to a value of 0.6 turns the sign of the economic insurance value to becoming negative. Overall, this underlines the importance of considering the risk aversion of farmers for the estimation of the economics value of resilience and in particular suggest that acquiring more robust empirical evidence on the CRRA-coefficient is of key importance for future studies.

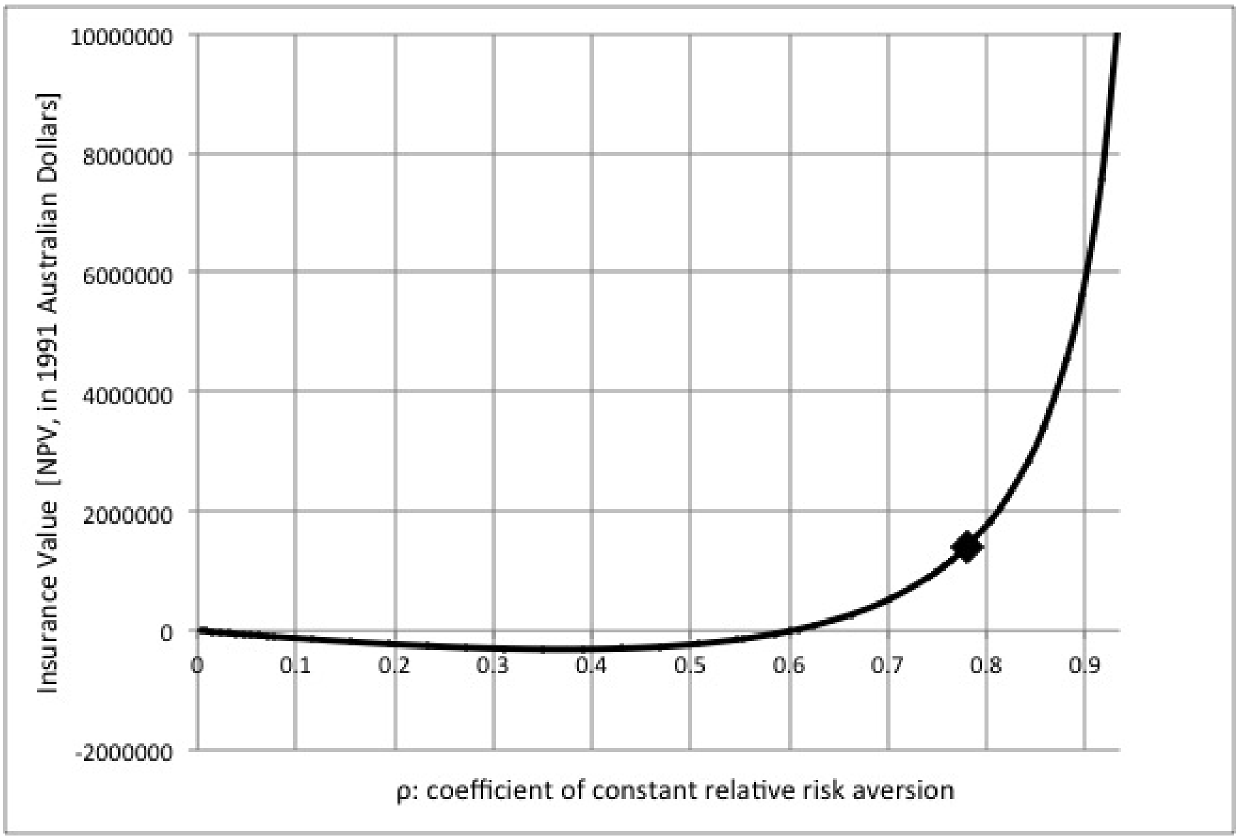

Figure 6: Sensitivity analysis of the economic insurance value of ecosystem resilience $I_{NPV}(R_0;T)$ with respect to the degree of (constant relative) risk aversion. The black diamond on the curve highlights the base assumption for ρ of 0.78.

6 Discussion

This paper is concerned with the quantification of the economic insurance value of resilience for the Goulburn-Broken Catchment (GBC) case study from South East Australia (see Walker et al. (2010)).

Resilience – i.e. the ability of a system to withstand shocks and undergo change while keeping its basic function and properties in working order – has been identified as a key system property for the assessment of a sustainable development (see, e.g., Arrow et al. (1995), Bateman et al. (2011) and Kates et al. (2001)), but only few studies exist that scrutinize the economic assessment of resilience. Furthermore, most approaches have interpreted resilience as insurance in a rather metaphorical way, while it has been shown that the economic insurance value of resilience is only one part of the total economic value of resilience (Baumgärtner and Strunz 2014). Analyzing the insurance value and the other component of the total economic value of resilience separately is important as they might have different man-made substitutes – the insurance value of resilience may be substituted by ordinary financial insurance contracts while other functions of resilience may not.

In order to estimate the economic insurance value of resilience for the GBC case study, this paper has combined the approaches of Walker et al. (2010), who provide an estimate of the economic value of resilience for the GBC case study, and Baumgärtner and Strunz (2014), who develop a simple ecological-economic model to derive the economic insurance value of ecosystem resilience.

The estimation of the economic insurance value of ecosystem resilience for the GBC case study in the year 1991 for a 40-year time horizon yields a value of 1,409,202$. This confirms that ecosystem resilience may indeed function as economic insurance for risk averse ecosystem managers – in this case the farmers in the GBC.

A sensitivity analysis, however, revealed that the insurance value highly depends on the degree of risk aversion of farmers in the GBC, who were assumed to exhibit constant relative risk aversion with a coefficient value of 0.78. Some further major assumptions that limit the explanatory power of the results shall be briefly recapitulated:

1. Market prices of land rents have been used to calculate the shadow price of land in the two regimes, which were assumed to be constant throughout the 40-year time horizon (this is a caveat that Walker et al. (2010) discuss in more detail);

2. Analysing this specified resilience necessitates the ceteris paribus assumption that all other relevant variables, some of which are most certainly not independent of water table dynamics, remain constant throughout the time frame of the analysis;

3. Although the analysis of water table dynamics as the key variable influencing the resilience of crop production in the GBC has been chosen with a focus on the situation of a single farmer, both Walker et al. (2010) and this study have assessed resilience for the GBC system as a whole. We have made the explicit assumption that all farmers in the GBC have the same risk preferences and are equally affected by changes in the water table (the data presented in Walker et al. (2010) are only based on historical water table changes from one bore in a central location in the GBC).

This discussion of the strong assumptions that had to be made for the resilience assessment in this study and that of Walker et al. (2010) represents a good starting point for a more general discussion on problems associated with the economic assessment of specified resilience. Since the capital pricing approach to resilience assessment developed by Mäler and others (see in particular Mäler and Li (2010)) analyzes specified resilience in a *Knightian risk* setting, detailed knowledge is in particular required about the location of the threshold and the cumulative probability that the system flips to the alternate regime. The fact that even economic resilience assessment for the GBC case analysed in this paper, which is deemed to be one of the best-studied ecosystems in the world (Walker and Salt 2006), still has to rely on the crude assumptions presented above, casts doubt on the universal applicability of this approach. Besides data availability seeming to be the most important limiting factor for elevating resilience assessment to a broader scale, the 'dimensional' reductionism of analysing one key variable only, on whose changes a possible regime shift depends, also represents a problem for more realistic resilience assessments (this challenge has been noted by Walker et al. (2010) but deferred for further research). The major problem with this reductionism is that by focusing too much on a specified resilience relationship that is driven by one key variable only, we might let other variables of the system degrade that will in turn threaten the resilience of the system from a very different angle (that is a narrow focus on specified resilience may lead to a lower general resilience of a system (Walker and Salt 2006). So even though most economic approaches to resilience assessment have focused on specified resilience up to this point, as this offers the opportunity of an assumption- and proxy-based quantification, the analysis of general resilience should always be pursued simultaneously to account for the various interactions that might threaten the sustainable development of a given system (this is what Walker et al. (2009; 2010) have done in two separate papers)

7 Conclusion

This paper has provided a modelling and assessment approach with which the economic insurance value of ecosystem resilience can be estimated for a setting with risk-averse ecosystem users. We find that the estimated insurance value has a large positive value of 1,409,202$– that is, resilience does indeed function as insurance for the risk averse farmers of the Australien Goulburn-Broken catchment. Yet, a sensitivity analysis has revealed that the magnitude and also the sign of the insurance value are sensitive to the degree of (constant relative) risk aversion.

There are a number of issues with the underlying data and the quantification of the insurance value had to rely on proxies in major stages of the evaluation process: First, market prices have been used instead of shadow prices for the calculation of the income loss due to a regime shift; Second, the flip probability has been estimated based on observations from one bore only and assumed to be similar all across the region; Third, insufficient empirical evidence could be gathered for a reasonably robust estimate of the degree of risk aversion. Because of these shortcomings in the evaluation of the total economic value, as well as the insurance value of ecosystem resilience, the potential of this specified resilience assessment for the the practice of sustainability measurement and management must be viewed with caution. Yet, such a specified resilience assessment is in particular needed for creating truly encompassing measures of progress such as the Inclusive Wealth Indicator (see Mäler (2008) and Walker et al. (2010)). As it is a necessary input to making efficient decisions that secure the livelihoods of risk-averse people around the world who are threatened from the abrupt loss of critical ecosystem services, further research on the economic insurance value of resilience is required.

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Appendix

A Proof of Equation 5

The riskiness of the income lottery (R_0, t) in period t is captured by its current value risk premium $\Pi(R_0; t)$, depending on the initial resilience stock and time t, that is the (maximum) amount of money that the farmer would be willing to pay at time t to receive the expected income for sure instead of having to play the risky lottery:

$$u(E_{R_0;t}[y] - \Pi(R_0; t)) = E_{R_0;t}[u(y)]. \tag{A.1}$$

With CRRA utility (Equation 3), the expression becomes

$$\frac{1}{1-\rho}\left(E_{R_0;t}[y] - \Pi(R_0; t)\right)^{1-\rho} = E_{R_0;t}\left[\frac{1}{1-\rho}y^{1-\rho}\right]$$

$$F(R_0; t)(y-\Delta y)+(1-F(R_0; t))y-\Pi(R_0; t) = \left[F(R_0; t)(y-\Delta y)^{1-\rho} + (1-F(R_0; t))y^{1-\rho}\right]^{\frac{1}{1-\rho}}$$

$$\Pi(R_0; t) = F(R_0; t)(y-\Delta y)+(1-F(R_0; t))y-\left[F(R_0; t)(y-\Delta y)^{1-\rho} + (1-F(R_0; t))y^{1-\rho}\right]^{\frac{1}{1-\rho}}$$

$$\Pi(R_0; t) = E_{R_0;t}[y] - \left(E_{R_0;t}[y^{1-\rho}]\right)^{\frac{1}{1-\rho}}. \tag{A.2}$$

B Proof of Proposition 1

to follow

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