On the design of water markets in the presence of risk aversion

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Introduction

- Farmers are facing a number of risks
- Farmers are known to be risk-averse in most situations
- Various tools for risk management:
  - On-farm risk management: diversification of activities, crop choice, input choice, technology adoption etc.
  - Markets: insurance markets, forward trading, water markets etc.
- In this paper: focus on risk due to uncertainty on water supply and rainfall, and water markets

Main purpose of the paper

To better understand the role of **water markets design** on the decision of risk-averse farmers, through:

- the effect of **initial water allocations** on farmers' choices between irrigated and non-irrigated production
- the consequences of implementing a **forward market** for water allocations on farmers' decision rules (not discussed today)

Tools: theoretical model describing farmer's behaviour + simulations calibrated on Australian data

Model features

- a risk-averse farmer receives an initial allocation of water (e_0)
- there is uncertainty on the price of water (r) and hence uncertainty on farmer's wealth (re_0) (background risk)
- at the beginning of the season, the farmer decides how much land to put into irrigated production (x); so $(1 - x)$ is put into non-irrigated production
- net returns of the irrigated activity (R) and of the non-irrigated activity (ε) are random because of water price uncertainty and uncertainty on rainfall patterns

Model features (cont'd)

- the farmer faces three risks that are not independent; we expect $corr(R, r) < 0$ and $corr(\varepsilon, r) < 0$
- we want to understand how the (risk-averse) farmer chooses x, i.e. the proportion of land allocated to the irrigated activity
- equivalent to a problem of portfolio selection with two risky assets and presence of a dependent background risk

Related literature

- Modelling of risk-averse farmer's decision under production/price risk
- Role of water markets as risk management tool for farmers
- Financial literature on portfolio selection with background risk
- Dependance of market outcomes from initial allocations in the presence of uncertainty and risk aversion (markets for pollution quotas)

Timing

1. the government decides on the initial allocations e_0
2. the farmer decides on the share x (ex ante decision with r and ε uncertain)
3. ε and r are realized
4. the farmer decides on the final quantity of irrigation water z (ex post decision)

Farmer's (ex-post) profit function

$$\pi(x, z) = (pf(z) - rz)\,x + (1 - x)\varepsilon + re_0$$

where

- x: share of land allocated to the irrigated production,
- z: quantity of irrigated water used for production,
- p: the (non-random) price of the irrigated product,
- r: the price of water on the market,
- ε: the per acre net benefit of the non-irrigated activity,
- e_0: the initial (per acre) water allocations.

In what follows, we will consider $R(r) = pf(z) - rz$, the per acre net benefit of the irrigated output.

Farmer's (ex ante) optimal decision on x^*

Expected utility framework: the (ex ante choice) of x is given by

$$\max_x V(x) \equiv E(U(w_0 + \hat{\pi}(x))$$

with $\hat{\pi}(x)$ the ex post maximized profit, w_0 the initial (certain) wealth, and $U(.)$ a concave utility function. The FOC is:

$$V'(x) \equiv E\left(U'\hat{\pi}'\right) = 0.$$

Because of the presence of risk aversion, the initial allocation e_0 enters in the ex ante choice x through a (random) wealth effect.

Question: what is the impact of risk aversion on the ex ante optimal choice x^*?

Claim

A risk neutral producer chooses $x = 1$ whenever $\bar{R} > \bar{\varepsilon}$ and $x = 0$ whenever $\bar{R} < \bar{\varepsilon}$. When $\bar{R} = \bar{\varepsilon}$ the farmer is indifferent between allocating land to irrigated and non-irrigated activities.

where $\bar{R} = ER(r)$ and $\bar{\varepsilon} = E(\varepsilon)$.

Proposition

The farmer's optimal decision rule under risk aversion is given by (interior solution):

$$x^* = \frac{\bar{R} - \bar{\varepsilon}}{\rho(\bar{w}(x, e_0))V(R - \varepsilon)} + \frac{V(\varepsilon) - Cov(R, \varepsilon)}{V(R - \varepsilon)} - \frac{Cov(r, R - \varepsilon)}{V(R - \varepsilon)} e_0$$

where $\rho(.) = -U''(.)/U'(.) > 0$ is the Arrow-Pratt degree of absolute risk aversion.

The decision x^* relies on the comparison of three terms:

1. *Mean effect*

$$\frac{\bar{R} - \bar{\varepsilon}}{\rho(\bar{w}(x, e_0))V(R - \varepsilon)}.$$

The decision to allocate some land to the irrigated crop depends positively on the comparison between expected revenues $\bar{R}$ and $\bar{\varepsilon}$.

Note: a farmer who receives a low initial allocation will put a lower weight on this factor if his preferences satisfy the DARA property.

2. *Variance effect*

$$\frac{V(\varepsilon) - Cov(R, \varepsilon)}{V(R - \varepsilon)}.$$

A higher variance of ε increases, ceteris paribus, x^*.

Furthermore, if R and ε are negatively correlated then there is an additional reason to invest in x in order to diversify the portfolio.

3. *Covariance effect*

$$-\frac{Cov(r, R-\varepsilon)}{V(R-\varepsilon)}e_0$$

The initial allocation of water plays a role in choosing x^* because its value r is random and potentially correlated with the revenue difference $R-\varepsilon$.

If the background risk re_0 and $R-\varepsilon$ are negatively correlated, then investing in x corresponds to a strategy to diversify risk.

Question: what is the role of e_0 on the ex ante optimal choice x^*?

The initial water allocation entails two effects on the optimal ex ante decision x^*:

(i) a "*pure wealth*" effect which, for DARA preferences, induces the agent to put a higher weight on the expected revenue difference $\bar{R} - \bar{\varepsilon}$ relative to the variability, following an increase in e_0,

(ii) and a "*background risk*" effect which gives incentives to the agent to increase x^* following an increase in e_0 if the random price of water r and the revenue difference $R - \varepsilon$ are negatively correlated. This is done in order to diversify the portfolio following an increase in e_0.

Question: what is the role of e_0 on the ex ante optimal choice x^*?

In the special case of CARA preferences, we have:

Corollary

Under CARA preferences, an increase in e_0 yields the agent to increase the share of land devoted to irrigated crop when $Cov(r, R - \varepsilon) < 0$ and to decrease x^* when $Cov(r, R - \varepsilon) > 0$.

In the general case, the relationship between x^* and e_0 is non monotonic $\rightarrow$ simulations.

Next steps

- Modelling farmer's behaviour when forward trading of water allocations is allowed.
- Simulations calibrated on Australian data:
  - Lognormal distribution for the price of water
  - Beta distribution for the net returns of the irrigated and non-irrigated crops
  - Simulation of random variables with some degree of dependence
  - Calibration using data from ABARES irrigation farm survey and NWC data on water transactions
  - Purpose: how x^* changes depending on the correlation between the three risks, the degree of risk aversion, and the level of water allocations

Main (preliminary) findings

- if the farmer is risk averse, his optimal choice of x^* (land allocated to irrigated production) does depend on the level of initial allocations e_0
- the level of initial allocations creates a background risk due to the uncertainty on the price of water
- e_0 entails two effects on x^*: a "*pure wealth*" effect and a "*background risk*" effect
- effects cannot be signed in general (except for the CARA case)
- simulations calibrated on Australian data