Option values and decision thresholds: towards a definition of economic resilience

Todd Sanderson - University of Sydney

Tim Capon - CSIRO

Greg Hertzler - University of Pretoria

Contributed presentation at the 60th AARES Annual Conference,
Canberra, ACT, 2-5 February 2016

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Todd Sanderson* (University of Sydney), Tim Capon (CSIRO), and Greg Hertzler (University of Pretoria)

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*Presenter (University of Sydney)

Economic resilience and option values

- We show how decision-making is fundamental to defining and measuring economic resilience.

- We show how new developments in the application of real options analysis to questions of optimal timing can be used to more clearly define and measure the concept of economic resilience.

- We show how economic resilience differs from alternative resilience concepts and provide a mathematical framework that can be used to evaluate the resilience of an economic regime.

A definition of economic resilience

- Economic resilience is the ability of an economic system to remain in a particular regime before reaching a decision threshold.
- It results from the properties of the system that enable it to remain in a particular regime.

    E.g. A high level of farm equity means the farmer can weather bad years

    E.g. A lack of funds for investing in a new technology needed for an alternative production regime (poverty trap)

This means that economic resilience can be good or bad.

Economic, ecological and engineering resilience

- This definition of economic resilience differs from common definitions of ecological and engineering resilience.
  - Ecological resilience is the ability of a system to absorb perturbations before entering an alternative regime with a new structure (Holling, 1963; Walker et al., 1969)
  - Engineering resilience is the speed a system displaced from equilibrium by a shock returns to that same equilibrium (Pimm, 1984; Holling, 1996).
- Instead, we define economic resilience in relation to decision thresholds between alternative economic regimes.

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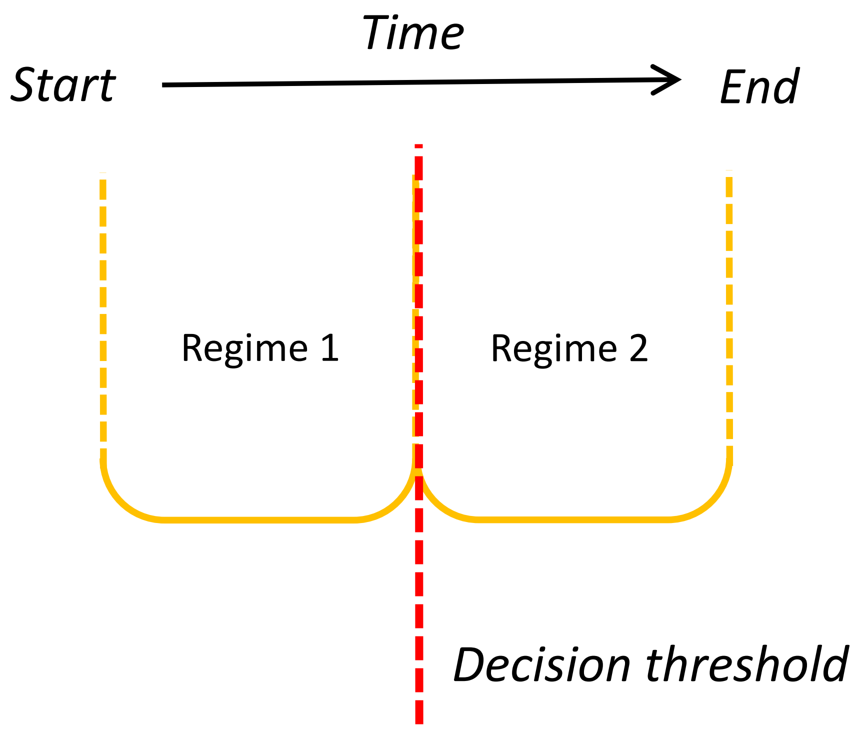
Importance of expectations

- Resilience in social systems is different to resilience in ecosystems because people are conscious of the future in a way that ecosystems are not (Holling and Walker, 2003).
- Knowledge of the current state of a regime in an economic system is not enough to understand its resilience, because time matters and people's expectations about the future affect their decisions.
- Our proposed definition of economic resilience reflects the importance of expectations for decision-making.

Decision thresholds and real options analysis

- A real options approach can be used to characterize the thresholds between alternative economic regimes and to measure economic resilience as the expected time until a system crosses a decision threshold.
- Consider an agent who must decide between alternative uses for scarce resources. This decision can be framed as a choice between alternative economic regimes.
- An economic regime is defined by the activities undertaken within it and can be described in terms of its unique system dynamics, its costs and benefits, and its uncertainties.

Alternative economic regimes



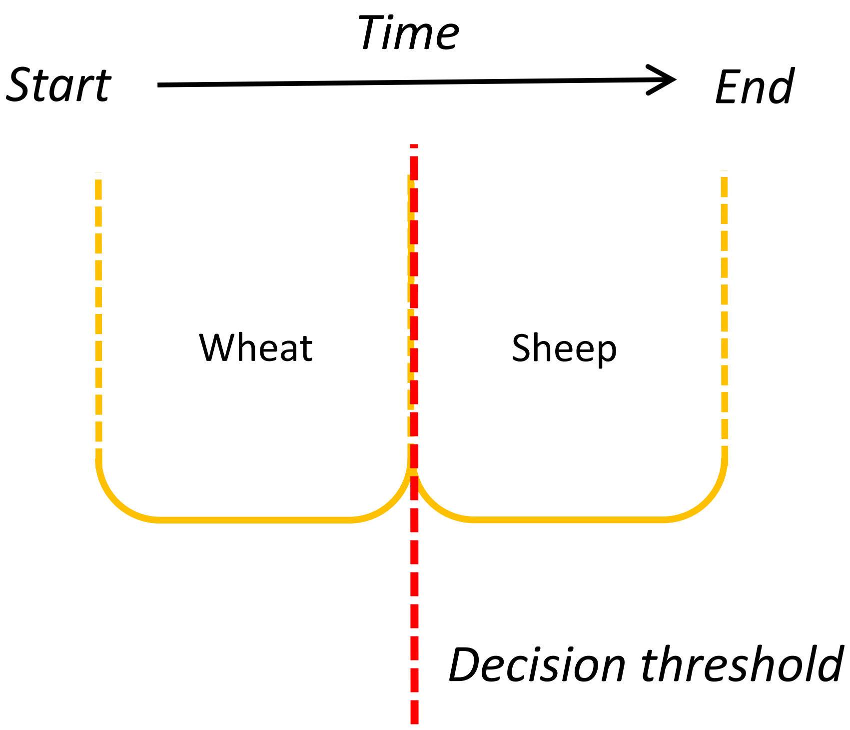
Decision thresholds

- For example, a farmer considering alternative uses for a parcel of land might decide between wheat production and sheep grazing. The boundary between these two alternative production regimes is a decision threshold.
- This decision threshold is affected by the famer's knowledge of conditions in the current regime and expectations about conditions in alternative regimes.
- Observing changing environmental, social and market conditions, the farmer may decide at any time to change from the current regime to an alternative regime.

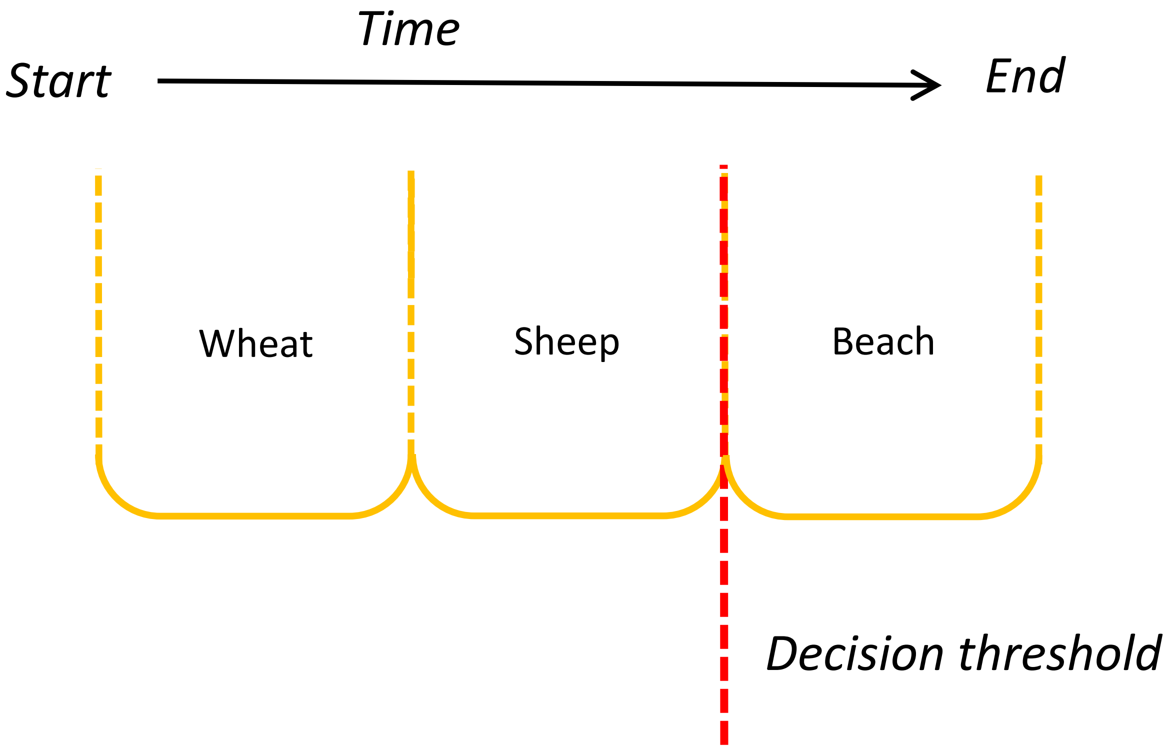
Decision thresholds

- Economic regimes can be defined so we can measure the resilience of wheat production or, in a system that transitions from wheat production to sheep production before finally leaving agricultural production, we could equally consider the resilience of agricultural production itself.
- We can measure the ability of an economic system to remain in a particular regime before reaching a decision threshold by estimating the expected time to a decision threshold.

Resilience of wheat production



Resilience of agricultural production



Decisions, option values and thresholds

- The first step is to define option value of the two regimes and associated state decision threshold, this process is a performed by solving the well known option pricing equations (1) and (2) for some stochastic process (3):

$$\frac{\partial W}{\partial t} - rW + \frac{\partial W}{\partial x} g(x) + \frac{1}{2}\frac{d^2 W}{dx^2} h^2(x) = 0 \quad (1)$$

$$W\{T, x(T)\} = V\{x(T)\} \quad (2)$$

$$dx = g(x)dt + h(x)dz \quad (3)$$

Resilience as a probability

- We can estimate the resilience of a given regime based on the probability of crossing a critical threshold (Perrings, 1998).
  - ➢ A probability is a function of the present state and time of the system, and some future state and time.

- There are two equivalent approaches to framing this probability, which arise directly from the state-time duality in dynamic systems (Naevdal, 2006)
  1. The first as a state-transition probability.
  2. The second as a time-transition probability, this is also known as a distribution of the first-passage times.

Resilience as a state-transition probability

- We can treat the state variable as random and consider resilience as the probability that within some given time period we cross a particular threshold

- A state-transition probability is a function of the present time s, the present state of the system x, and a random expression of the system y which can occur at some future time t

- For example, the Ornstein-Uhlenbeck density is given by:

$$f(s,x,t,y) = \left\{\frac{b^{0.5}}{\pi^{0.5}\sigma\left(1-e^{-2b(t-s)}\right)^{0.5}}\right\} e^{-b\left\{\frac{\left[(y-\mu)-(x-\mu)e^{-b(t-s)}\right]^2}{\sigma^2\left(1-e^{-2b(t-s)}\right)}\right\}}$$

Resilience as a time-transition probability

- We can treat time as a random variable simply because we cannot be certain how long we will wait before the system delivers us to the threshold and causes a switch in regimes

- A time-transition probability is a function of the present time s, the present state of the system x, and a random expression of time t, which corresponds to the observation of some state y

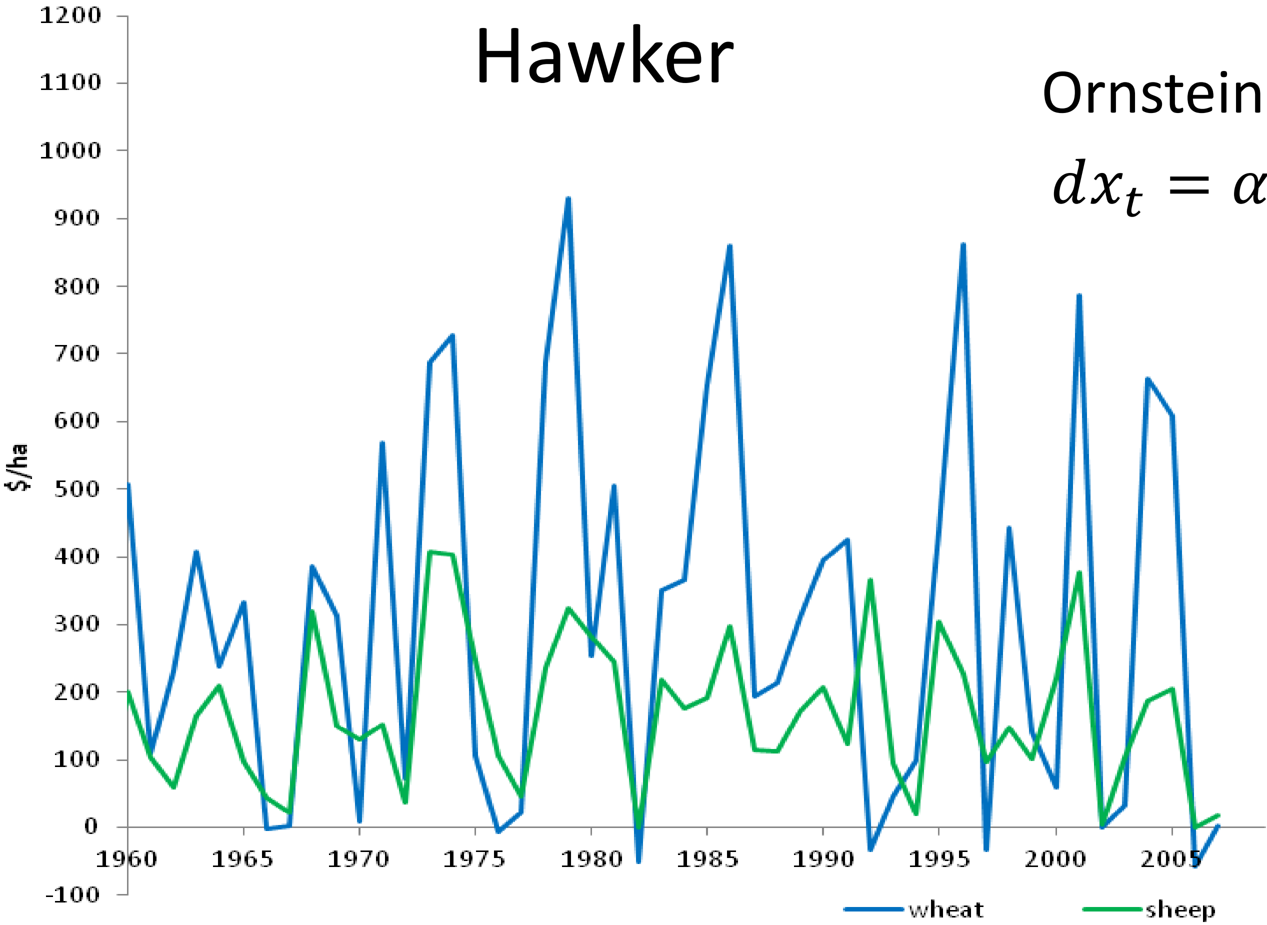
- Approach to identification is largely via numerical simulation of the estimated stochastic system
  - Conveniently, if *dz* is Brownian motion, the time-transition densities should be of an Inverse-Gaussian form

An illustration:
The South Australian wheat/sheep belt

Process:

- Step 1: gather data on the system, estimate appropriate stochastic process
  - APSIM generates yield/pasture growth series based on climate data files for Clare, Orroroo and Hawker in SA
  - Given assumed prices, estimate Ornstein-Uhlenbeck processes for gross margins
- Step 2: use estimated process and other switching cost information to estimate option values and regime thresholds
- Step 3: use bits of 1 and 2 to estimate regime state and time transition probabilities
  - Interpret as resilience of current regime to climate at a given location for given assumptions

Hawker

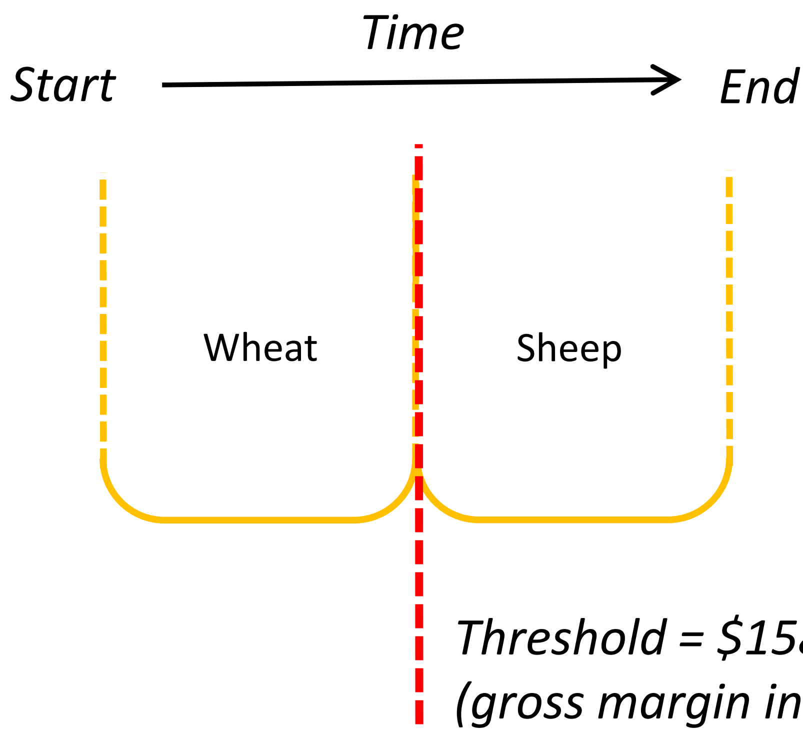


Ornstein-Uhlenbeck process:

$$dx_t = \alpha(\mu - x_t)dt + \sigma dz_t$$

	Regime	α	μ	σ	CV
Hawker	Wheat	0.940	328.7	314.7	0.698
	Sheep	0.891	157.6	111.9	0.532

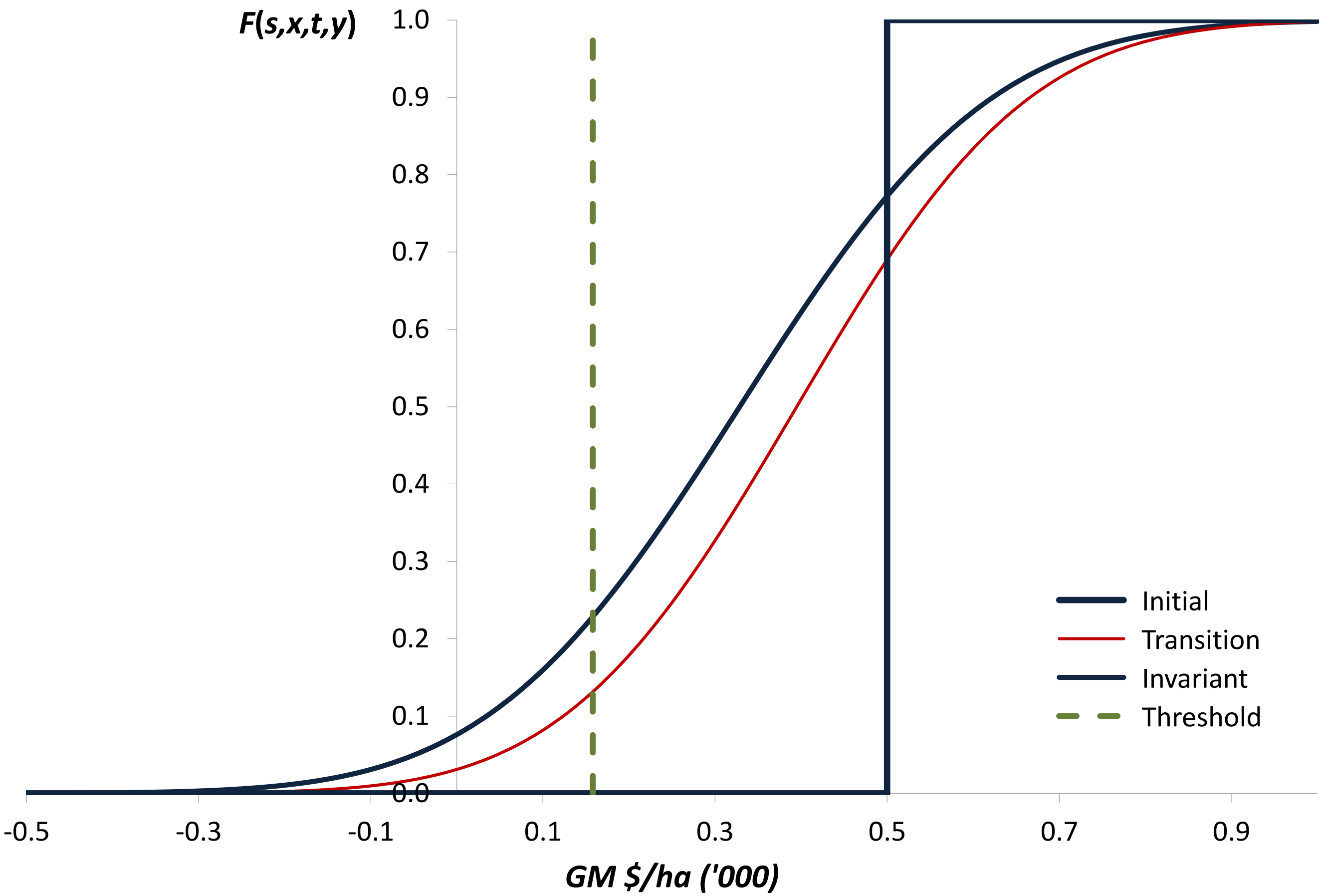
Wheat to sheep at Hawker



Threshold = $158/ha
(gross margin in wheat)

Option value = $221/ha

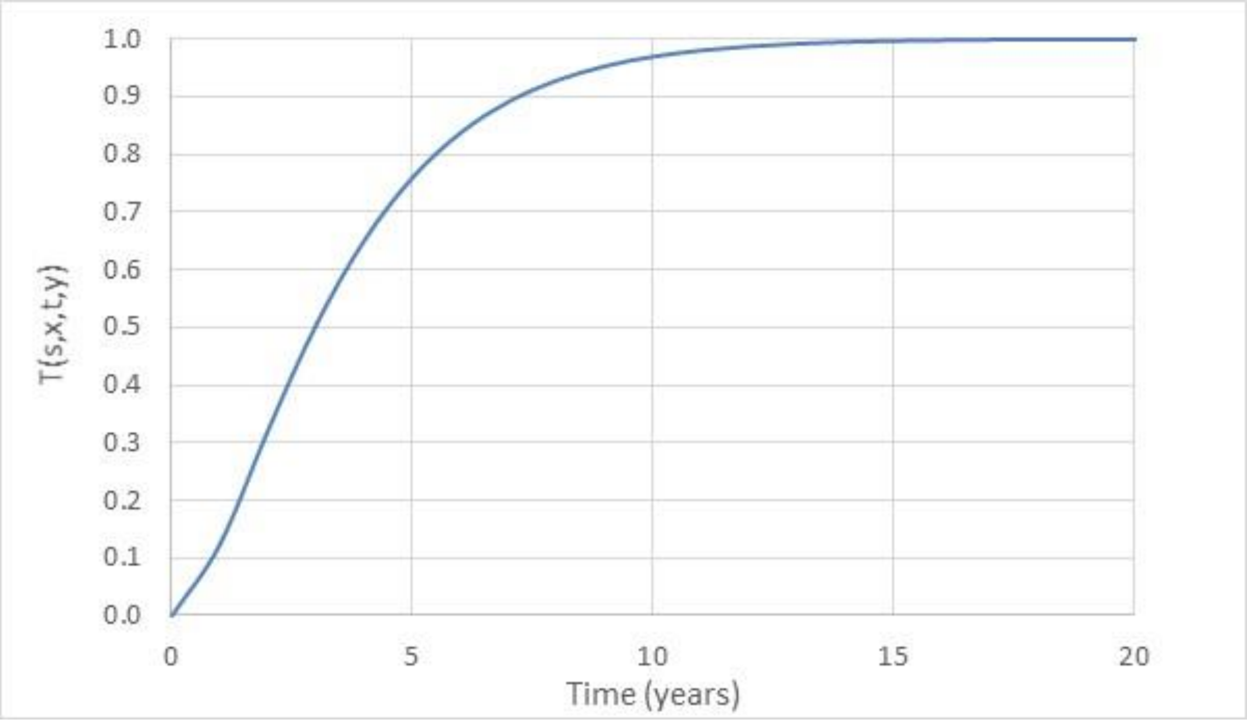
Cumulative state-transition probability at Hawker



Time Horizon (years)	State-transition probability
0	0.00
1	13.04
2	19.28
3	21.49

Initial state (t=0) gross margin: $500/ha

Cumulative time-transition probability at Hawker



Time Horizon (years)	time-transition probability
0	0.00
5	76.00
10	96.94
15	99.67
20	99.97

Initial state (t=0) gross margin: $500/ha

Expected time to threshold = 4.1 years

Economic resilience and option values

This perspective on economic resilience is important because

1. The thresholds between alternative economic regimes can be characterized as decision thresholds
2. We can use concepts of dynamic probability, and
3. We can summarize the expected time to a threshold without requiring a system to have stable attractors.

This means that the approach is relevant to a broad range of economic contexts and applications.

Further questions

- What does the estimated option value tell us about the value of resilience?
  - Option value surface is convex, so marginal option value rises as we approach the threshold
  - The marginal value of resilience changes as we approach a threshold and depends on the desirability or undesirability of that form of resilience

- Economic regimes are complex interacting functions of social, market and biophysical systems
  - A more complete quantification might require analysis with more than one stochastic process, and
  - These processes may be interdependent