A Dynamic Regional Model of Irrigated Perennial Production

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Brad Franklin, Keith Knapp, Kurt Schwabe

Introduction
Perennials as Dynamic Investment
Perennials are dynamic investments that have long-lived, commercially viable lifespans of 30 years or more. These crops are typically associated with low yielding but long-lived production. There are large fixed costs from new plantings and removal, but relatively low annual costs to maintain. Perennials are thus robust to weather shocks and have high water use efficiency. Despite these advantages, perennials are not widely adopted in irrigated agriculture. This is due to the lack of robust modeling of the economics of these crops. The below model develops a dynamic, economic model of perennial irrigation that is robust to weather, market price, and input variation.

Research Question
Perennials are dynamic investments that have long-lived, commercially viable lifespans of 30 years or more. These crops are typically associated with low yielding but long-lived production. There are large fixed costs from new plantings and removal, but relatively low annual costs to maintain. Perennials are thus robust to weather shocks and have high water use efficiency. Despite these advantages, perennials are not widely adopted in irrigated agriculture. This is due to the lack of robust modeling of the economics of these crops. The above model develops a dynamic, economic model of perennial irrigation that is robust to weather, market price, and input variation.

Policy Context
Riverland region, South Australia
2/3 irrigated area in perennials (Wine grapes)
Market power in fresh potatoes
Murray-Darling Basin river flows are highly variable
Millennium drought (1997–2009)

Policy Questions
How will proposed water purchases by the environmental water holder (up to 25% of total rights) affect irrigated agriculture?

Model Description
Representative farming household
1 annual, 1 perennial crop
Demand curve for annuals
Land and water constrained
Joint consumption, investment decisions

Dynamic Optimization
Running Horizon algorithm approximation to infinite horizon DP
Vintage structure
Initial age distribution of perennial crop
Utility function specified

Model Scenarios

<table>
<thead>
<tr>
<th>Land Binding</th>
<th>Water Binding</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Annuals</td>
<td>Assets</td>
</tr>
<tr>
<td>No Assets</td>
<td>No Assets</td>
</tr>
<tr>
<td>No Annuals</td>
<td>Mira et al.</td>
</tr>
</tbody>
</table>

Validating the model against Mira et al. (1991) for the case of only perennial production, no household assets, and land is the constrained resource.

Borrowing and Saving
- Borrowing rate > Savings rate
- Interest rate increases with debt held
- Schedule exogenous

Mathematical Description

Objective function and related equations

\[ c_t = (1 + r)\alpha_t \delta_t + \pi_t \]

\[ \pi_t = \pi_t + \pi_{t+1} + \pi_{t+2} \]

\[ \pi_{t+1} = \gamma_t w_{t+1} + \gamma_{t+1} w_{t+2} \]

\[ \pi_{t+2} = \gamma_{t+2} w_{t+3} + \gamma_{t+3} w_{t+4} \]

Constraints and Laws of Motion

Perennials LDM

\[ a_{t+1} = a_t - z_t \]

Asset LDM

\[ a_{t+1} = (1 + r)\alpha_t \delta_t + \pi_t + a_t \]

Cross-Vintage Constraint

\[ a_{t+1} + c_t \leq a_t \]

Land Constraint

\[ \sum_{t=1}^{\infty} a_t + b_t + z_t \leq V_t \]

Water Constraint

\[ \sum_{t=1}^{\infty} a_t + b_t + z_t + w_t \leq \bar{V}_t \]

No Ponzi Game

Results

The below shows selected results from a run of the full model. The household starts with no perennial and no financial assets and borrows a large amount initially to establish the perennial crop. As the crop matures, profit increases, allowing the household to increase consumption and accumulate savings. At the optimal removal age, the cycle begins anew. Log utility causes consumption smoothing over time and eventual convergence to steady-state land distribution. Also, a relatively high discount rate implies that it is optimal for the household to hold debt.

Extensions

One obvious extension to the model is to allow for deficit irrigation. Using a field-level DP model, the plot below shows grape yield as a function of current period water application and biomass index, which encapsulates water history of the crop. The dynamics implied by this model can be summarized and included in the regional model for each age class in production.

References


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Annual supply response to water variability. For water scarce regions, perennials are very important in some regions and are often irrigation-dependent. For example, they constitute roughly 1/3 of the total crop value in California.

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Graphical representation of annual returns to wine grape production in South Australia assuming constant prices.

Research Question
Perennials crops are dynamic but the agricultural production programming literature is basically static.

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