Towards an Economic Rationale for Sustainable Groundwater Management

by

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Managing Resources for Sustainability

• Within the Natural Resources field, sustainability is a key topic of discussion and concern
• Much of it stems from the literature on inter-generational welfare and social justice (the ‘right’ of future generations to have the same amenities or standards of living as current ones)
• A lot has dealt with the technicalities of model specification and how to capture the inter-temporal tradeoffs properly -- from the point of view of the “Social Planner”
• Many of the same arguments of social justice and inequality in a static sense, can also be applied here
Sustainability within the Current Context

• But to a wider audience, sustainability means something perhaps less technical but more fundamental to what people care about (both politically and morally)
• “Is there going to be enough groundwater 5 years from now” is what a farmer in the Central Valley is concerned with (more so than what’s left for future generations of farmers….)
• The more theoretical literature on sustainability has not always been good at addressing the concerns of the public in a way that can be appreciated and well understood
• Is there a way to bring farm-level technologies into the analysis to make the discussion more relevant to the resource problems we now face?
Sustainability of Resources for Agriculture

- We look at some of the underlying technical issues of sustainability, and how it can be represented within the preference structure of a dynamically-thinking Planner.
- We also put it within the context of growth and agriculture, so that it can have more meaning to some of the issues currently being faced by policy makers and resource managers.
- As always, there is a fundamental trade-off between competing objectives, and over scarce resources.
- Specifying the problem correctly is important, from the point-of-view of behavior – but the specification of the technological possibilities might be even more important.
- Boils down to substitution – both intertemporal and technological.
Outline of Presentation

• Present the dynamic model to be used

• Highlight the features of inter-temporal and technological substitution

• Examine its behavior over a range of parameter specifications, and the trade-offs between financial and natural resource capital

• Draw conclusions on the important elements driving sustainability
Dynamic Growth Model with Groundwater Extraction
Economic Model of Growth

Net benefit function with groundwater pumping costs

\[ B(w, c) = a \cdot \log(c) - e \cdot (\bar{s} - h) \cdot w \]

where the marginal cost of extraction depends on the “lift”

\[ (\bar{s} - h) \]

Groundwater levels evolve dynamically over time

\[ h^+ = h - \gamma \cdot w + \tilde{R} \]

As does the stock of capital used in production

\[ K^+ = A \cdot \left[ \theta K^\alpha + (1 - \theta)w^\alpha \right]^\frac{1}{\alpha} - c \]
Stylized Single-Cell Aquifer

\[ h_{t+1} = h_t - \frac{(1 - \phi) w - R}{A \cdot s_y} = h_t - \gamma \cdot w + \tilde{R} \]
Standard Problem of Dynamic Allocation

A centralized resource management scheme would consider the long-term social benefit of groundwater extraction and capital accumulation by solving the following problem

\[ V(h, K) = \max_{w,c} \left\{ a \cdot \log(c) - e(\bar{s} - h) \cdot w + \beta \cdot V(h - \gamma w + \bar{r}, A \cdot \left[ \theta K^\alpha + (1 - \theta)w^\alpha \right]^{\frac{1}{\alpha}} - c \right\} \]

Whose solution defines the optimal ‘policy rules’ for both groundwater extraction and capital accumulation

\[ w = f\left(h, K \mid \alpha, \beta, a, e, \bar{s}, \bar{R}, \theta, \gamma\right) \quad , \quad c = g\left(h, K \mid \alpha, \beta, a, e, \bar{s}, \bar{R}, \theta, \gamma\right) \]
An Critical Behavioral Assumption Underlies This Kind of Model

• In most studies which look at resource management or extraction with respect to a dynamically-behaving Central Planner have maintained a rather strict behavioral assumption

• Time-additive Separability (TAS) of the objective criterion places a severe restriction on inter-temporal substitution behavior (only consumption in adjacent periods matter – now and next period)

• To sum it up -- it assumes “the marginal rate of substitution between lunch and dinner is independent of what you had for breakfast”

• Anyone who missed or skimped on their breakfast, this morning, realizes that this is not true (right about now….)
Recent Literature Has Begun to Uncover its Implications for Natural Resource Problems

- Knapp and Olson (1996) showed the implications of relaxing this assumption in a variety of standard resource problems.
- Howitt et al. (2005) showed that TAS is incompatible with reservoir management behavior in an empirical study of Oroville.
- The Finance and Macro-economic literature is ahead of the natural resources management field in studying this issue.
From TAS to Recursive Utility

- Koopmans (1960) laid the foundation for eliminating deficiencies of TAS with recursive preferences.
- Recursive Utility is a class of functionals designed to offer a generality to time preferences while still maintaining time consistency in behavior.
- Allows for the potential smoothing of consumption by allowing complementarity between time periods.
Koopmans’ Equation

States the weak separability of the future from present

\[ U(c) = W(u(c_1), U(SC)) \]

where

\[ W(\square) \] is an aggregator function

For TAS, the aggregator is simply

\[ W(u(c), y) = u(c) + \beta y \]

\( c = \) consumption
\( S = \) a scalar mapping of vector of future consumption
\( y = \) benefit from next period onward
\( \beta = \) discount factor
So we choose our aggregator to be

\[ W(u(c), y) = \left[ (1 - \beta) \cdot u(c)^{\rho} + \beta \cdot y^{\rho} \right]^{\frac{1}{\rho}} \]

\[ \rho \in (-\infty, 0) \cup (0, 1] \]

where

and the implied elasticity (“resistance”) to inter-temporal substitution is given by

\[ (EIS) \quad \sigma = \frac{1}{1 - \rho} \]
Dynamic Behavior in Recursive Utility Formulation

\[
V(h, K) = \max_{w,c} \left[ \left(1 - \beta\right) \left(a \cdot \log(c) - e(\bar{s} - h) \cdot w\right)^{\frac{1}{\rho}} + \beta \left( V \left( h - \gamma w + \bar{r} , \left( A \cdot \left[ \theta K^\alpha + (1 - \theta) w^\alpha \right]^{\frac{1}{\alpha}} - c \right) \right) \right)^{\frac{1}{\rho}} \right]
\]

Now the central planner manages the groundwater basin in a way that is path dependent and which takes more than just the adjacent periods into account when making inter-temporal trade-offs.
Implications for Inter-temporal Behavior
Behavioral Experiments

- Now let’s investigate the effect of changes in the substitution parameters (for inter-temporal behavior and technology) on groundwater usage and capital accumulation over time.

- Allows us to examine the relative importance of these parameters to the long-run state of the natural resource.

- Brings to focus the underlying nature of the decision-maker’s problem:
  - The substitution of consumption benefits between periods.
  - The substitution of financial capital for natural resource capital in the production of the consumption goods.
Implications of Inter-temporal Substitution on GW levels

GW table sinks lower as the “lift” increases

Lower willingness to substitute b/w periods

![Graph showing GW levels over time with different scenarios.](image-url)
Implications of Inter-temporal Substitution on Long-Run Capital Stock

Long-run steady-state capital stock decreases
Lower willingness to substitute b/w periods
Implications of Inter-temporal and Technological Substitution on GW Levels

Lower willingness to substitute b/w periods

Increasing ability to substitute b/w capital and water

Long-run steady-state GW stock increases as “lift” goes down
Implications of Inter-temporal and Technological Substitution on Capital Stock

- Lower willingness to substitute between periods
- Long-run steady-state capital stock increases
- Increasing ability to substitute between capital and water
Implications of Inter-temporal and Technological Substitution on Consumption

- Lower willingness to substitute between periods
- Increasing ability to substitute between capital and water
- Consumption level increases
Implications on Consumption/Water Ratio

Increasing substitution b/w water & capital

Greater willingness to substitute benefits between periods

Lower willingness to substitute benefits between periods

\[ \rho = 1; \alpha = 0.1 \]
\[ \rho = 1; \alpha = 0.34 \]
\[ \rho = 1; \alpha = 0.66 \]
\[ \rho = 0.1; \alpha = 0.1 \]
\[ \rho = 0.1; \alpha = 0.34 \]
\[ \rho = 0.1; \alpha = 0.66 \]
The Ability to Substitute Matters

• The effect of changes in the substitution parameters (for inter-temporal behavior and technology) is consistent across the indicators.

• But the technological substitution has greater implications for the state of groundwater than the degree of inter-temporal substitution (for the ranges shown).
  • Greater ability to substitute (technologically or intertemporally) means you build up financial capital quickly so you can run it down later, in lieu of the GW stock.

• Demonstrates that the specification of behavior and technology matters.
  • One aspect deals with the preferences of the decision-maker.
  • The other dimension deals with the decision-maker’s ability to substitute one type of capital for another.
Example of Irrigation Efficiency and Cost of Capital

Implications for Technology in Agriculture

• Drawing from the example of California agriculture, we can see where financial capital can be substituted for water usage – in the case of capital-intensive drip irrigation systems, or other water-saving technologies.

• Trade-off is between water-saving or capital-saving production methods.

• Can easily apply to other depletable resources, whose intensive use can be substituted for capital-intensive production methods (or consumption technologies).
  • Fossil fuel consumption – although technology changes are usually ‘forced’ through high price conditions.
Insights and Implications
Implications for How Dynamic Behavior is Modeled

• Need to move towards more “flexible functional forms” in the specification of inter-temporal preferences

• In the time-additive separable case, the discount rate is the only behavioral parameter that can affect inter-temporal behavior – but there’s more than just discounting

• This matters even more when we move to the case of uncertainty and risk – where we need to distinguish between trading-off between time periods and alternative ‘states-of-the-world’

• Has strong implications for empirical work, and how we can estimate dynamic behavioral models
Important of Substitution Possibilities

- The prospects for sustainability depend not only on the preferences of the extracting agent, but also on the technological possibilities she faces.

- The CES is not the only technology that could lead to greater flexibility in input substitution for production – but illustrates it most clearly.

- The literature on sustainability often argues on the ethics of leaving future generations with less of the natural resource, but the equivalent amount of capital that can bring them to the same level of utility.

- Perhaps not all types of resources can be substituted in this way – which implies a lower elasticity of substitution.
Conclusions

- Revisit the way in which we model dynamic decision problems to allow for more flexibility.

- Technologies might promoting sustainability by enhancing the flexibility to substitute between different forms of capital (financial/natural) -- perhaps not in all cases.

- While these results still have implications for inter-generational welfare trade-offs, they apply to a much more immediate set of policy issues that have tremendous importance for resource management problems and policy.
Thank you!