Optimal Split and Merge: Method and Application to Marine Reserve Management

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Split and merge in a dynamic setting

- Our paper introduces a formulation where a decision maker can both control and merge/split state variables.

- The new formulation is illustrated with an application in marine reserve management.
Application to Marine Reserves

- Role of marine reserves.
- Model of marine reserves without split and merge
- How a ‘split and merge’ strategy helps
- Technique to solve the new formulation
- Final remarks
Role of marine reserves

- Marine reserves have been known as a measure to reduce ecological threats from fishing activities but were economically inefficient.

- More specifically, harvest control would suffice if there were no shocks to fish stocks, and setting a reserve just restricts fishing opportunities.

- However, if fish stocks suffer from negative shocks (e.g. those caused by fishing activities), then marine reserves act as buffer zone, helping the stocks recover faster and may improve fishing returns (Grafton, Kompas and Pham 2006).
A dynamic model of marine reserves

- Marine reserves split fish population into protected and exploitable stocks

\[ T(s_E, s_R) = \phi \left( \frac{s_R}{R} - \frac{s_E}{1 - R} \right) \]

- When the cost of splitting and managing the reserve is not too high, it is optimal to keep the sites split.

- Our question: If so, why merge the sites (deregulation)?

Without negative shocks, reserves are inefficient

After a shock, reserves help recover faster

Optimal harvest (as ratio to MCC)
Fixed reserves v.s a (temporary) deregulation

No reserve  \[ R = 1 - R \]

More populous area fished and fish transfer

Setting a reserve in response to possible shocks

\[ R = 1 - R \]

A shock occurs

Fishers wait for a recovery

Regulated harvest

\( E = 1 - R \)
Fishers have an immediate access to higher density reserve, rather than fishing in low density exploitable site.

- Negative shocks explain not only why setting reserves but also why deregulating reserves temporarily.
Technique to solve the new formulation

- We use dynamic programming approach. The structure of dynamic programming equations remains:

\[
\text{Value from today} = \max \{ \text{Current return} + \text{Value from tomorrow} \}
\]

Reserves (de)activated? \quad \text{Split/merge}
Fish stock(s)? \quad \text{Harvest otherwise}

- Two value functions involved: (i) uni-variate when starting with no reserve (single state system) and (ii) bi-variate when starting with a reserve (2-state system). Optimal control must be able to tell what should be done in each situation.

- Common techniques do not work, and a new technique using linear programming is applied. The dynamic programming equation is approached as (weak) inequalities from which the two value functions can be approximated.
A numerical approximation of the new formulation

Concavity implies a balance is preferred

Hence, a short deregulation may balance the stocks
Final remarks

- Dynamically optimal ‘split and merge’ models can be applied in many areas: reserves for bio-security, reserves for food security, optimal investment, optimal consumption and so on.

- Negative shocks not only support the role of reserves but also explain why reserves may be temporarily deregulated.

- A short deregulation of reserves can improve fishing return as fishers have an immediate access to high density area rather than waiting for a gradual recovery.
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