Collective targeting in rural policies: review of proposed mechanisms and assessment of irrigation infrastructure measures in Emilia- Romagna

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Introduction

- **Topic:**
  - Rural policies on natural resource management
  - Proper target: group of farmers (vs individual farmers)
    - Public good
  - Incentives for coordinated environmental efforts
    - Payment for environmental practices
    - Premium/bonus “if” coordination
  - Minimum participation rules
    - Minimum number of agents
    - Minimum extent of land contracted
Introduction

• Objective:
  1. Review of policy and literature
  2. Potential of Cooperative Game Theory (CGT):
     • Focus on minimum participation rules in rural policy (natural resource management)
     • Effect of threshold on benefits distribution

• Cooperative Game Theory
  • Communication - Binding agreement – superadditivity: pareto efficiency is no problem
  • Focus on the distribution of the benefits
  • Shapley Value (SV): attributes the value of a cooperative venture

• Application to Emilia-Romagna
  • Rural Development Plan measure 125
Background: policy

- **EU (Biodiversity):**
  - Collective implementation of the “greening” constraints
  - Group of farmers as recipients of agri-environment-climate payments

- **Emilia-Romagna** *(water quantity)* incentivizes collective reservoirs
  - Two sets of eligibility constraints for the potential projects: one on the minimum size of the reservoirs (greater than 50000 m$^3$), one on the minimum number of farmers participating (20)

- **Emilia-Romagna** *(Biodiversity):*
  - “environmental contracts”

- **France** *(water quality):*
  - Payments for buffer strips are increased by 20% if at least 60% or the river bank is not cultivated (Dupraz et al., 2009)
Background: literature

• Biodiversity: agglomeration bonus/payment (Parkhurst et al. 2002)
  • Little on bargaining issues
  • Little on the distribution of the benefits
  • Mostly based on Non Cooperative game theory

• Irrigation water (quantity) (Ostrom, 1990)
  • Little on relationship between policy / socio-ecological systems
  • Benefit distribution (Janssen et al., 2011)
Background: literature

• Biodiversity: agglomeration bonus/payment
  • Experiments:
    • Communication (Parkhurst et al. 2002)
    • Network size (Banerjee et al. 2012)
    • Information availability (Banerjee et al. 2014)
  • Mathematical programming model
    • Policy effectiveness (Albers et al., 2008; Dupraz et al., 2009)
    • Global optimization objective function (Bamière et al., 2013; Drechsler et al., 2010),
    • Side-payments (Wätzold and Drechsler, 2013)

• Irrigation water (quantity)
  • Lack of a central coordination (Ostrom, 1990)
Cooperative Game Theory

- Coalitions
- Characteristic function
- Solutions
Cooperative Game Theory

- Coalitions: groupings of players
  - Modelling
    - Minimum participation rules
    - Spatial relations
    - Social relations
  - grand-coalition: when all the players work together
  - coalitions: possible sub-groups
Cooperative Game Theory

- **Characteristic function**
  - Attributes a value to the coalitions
    - Policy incentives
  - **Super-additivity** \( v(N) \geq v(s) + v(t) \)

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Cooperative Game Theory

- Solution: distribution of the worth
  - \( u_i^* \): worth attributed to the \( i^{th} \) agent in the grand-coalition
Solution: core

The “core”: rationally acceptable grand-coalition worth allocation (Gillies, 1959):

Individual rationality

\[ u_i^* \geq v(\{i\}) \quad \forall i \in N \]

Group rationality

\[ \sum_{i \in S} u_i^* \geq v(s) \quad \forall s \in S \]

Efficiency:

\[ \sum_{i \in S} u_i^* = v(N) \]
The Shapley Value:
  • unique solution
  • surely in the core if convex game (Shapley, 1971, 1952):

\[ u^*_i = u^{sv}_i = \sum_{\substack{s \subseteq N \\ i \in S}} \frac{(n-|s|)!(|s|-1)!}{n!} \left[ v(s) - v(s - \{i\}) \right] \]

The worth attributed to the \( i^{th} \) player through the SV is given by its average marginal contribution for any possible grouping of the players.
Solution: Shapley Value

- The Shapley Value:
  - unique solution
  - surely in the core if convex game (Shapley, 1971, 1952):

\[
\bar{u}_i^* = u_i^{sv} = \sum_{\substack{s \subseteq N \atop i \in S}} \frac{(n - |s|)!(|s| - 1)!}{n!} \left[ v(s) - v(s - \{i\}) \right]
\]

The worth attributed to the \(i^{th}\) player through the SV is given by its average marginal contribution for any possible grouping of the players.
Characteristic function

Problem:
• N farms have to build a irrigation reservoir
• Pooling resources to build the reservoir
• Financial support of the RDP – minimum participation rules
Characteristic function

The value for any possible coalition is given by:

$$\max \left[ R - (1 - \alpha P) k(Q_s) \right]$$

Revenues:

$$R = \sum_{i \in s} f^i(Q_i)$$

Costs:

$$k(Q_s)$$

Policy participation:

$$P = \begin{cases} 1 & \text{if } Q_s \geq q^t \\ 0 & \text{if } Q_s < q^t \end{cases}$$

Assume $k(Q_s)$ exhibits economies of scale ($k'(Q_s) > 0$ and $k''(Q_s) < 0$) -> grand-coalition is the most efficient group arrangement
Theoretical analysis

- **Solutions**
  - With financial support
    \[
    f^i_{Q_i} = f^j_{Q_j} = \alpha k^Q_{s*}
    \]
  - Without financial support
    \[
    f^i_{Q_i} = f^j_{Q_j} = k^Q_{s*}
    \]

- \(Q_{s*}^P\): water quantity of coalition financially supported by the policy if no threshold

  \[
  \begin{align*}
  \nu(s) = \begin{cases} 
  \Pi^P_s & \text{with } Q_s^* = Q_{s*}^P \text{ if } Q_{s*}^P \geq q' \\
  \Pi^{P,t}_s & \text{with } Q_s^* = q' \text{ if } Q_{s*}^P < q' \text{ and } \Pi^{P,t}_s \geq \Pi^{NP}_s \\
  \Pi^{NP}_s & \text{with } Q_s^* = Q_{s*}^{NP} \text{ if } Q_{s*}^P < q' \text{ and } \Pi^{P,t}_s < \Pi^{NP}_s 
  \end{cases}
  \end{align*}
  \]

- Increasing the threshold make the financial support more and more costly up to the point where the coalition withdraw from the policy
Theoretical analysis

- \( v(A) = 0 \)
- \( v(B) = 0 \)
- \( v(C) = 0 \)
Theoretical analysis

v(A) = 0
v(B) = 0
v(C) = 0

Grand-coalition worth
Share attributed to A
Theoretical analysis

- Individual rationality
- Group rationality
- Core

$v(A) = 0$
$v(B) = 0$
$v(C) = 0$
Theoretical analysis

Shapley Value

v(A) = 0
v(B) = 0
v(C) = 0
Theoretical analysis

\[ v(A) = 0 \]

\[ v(B) = 0 \]

\[ v(C) = 0 \]

“Low” threshold:

\[ v(B, C) = \prod_s^P \]

\[ Q_s^{*,P} \geq q_t, \text{ low} \]

\[ P = 1 \]
Theoretical analysis

"Low" threshold:
\[ v(B,C) = \prod_s P \]
\[ Q_s^{*,P} \geq q^t_{low} \]
\[ P=1 \]

"High" threshold:
\[ v(B,C) = \prod_s NP \]
\[ Q_s^{*,P} < q^t_{high} \]
\[ P=0 \]
Theoretical analysis

“Low” threshold:
\[ v(B, C) = \prod_s^P \]
\[ Q_s^{*,P} \geq q_t^{\text{low}}, \text{low} \]
\[ P = 1 \]

“High” threshold:
\[ v(B, C) = \prod_s^{NP} \]
\[ Q_s^{*,P} < q_t^{\text{high}}, \text{high} \]
\[ P = 0 \]
Theoretical analysis

"Low" threshold:
\[ v(B,C) = \prod_s P \]
\[ Q_s^{*,P} \geq q^t, \text{low} \]
\[ P=1 \]

"High" threshold:
\[ v(B,C) = \prod_s NP \]
\[ Q_s^{*,P} < q^t, \text{high} \]
\[ P=0 \]
Data and Scenarios

• Application to the Emilia-Romagna RDP

• Secondary data for revenue functions (Zavalloni et al 2014)
  • 3 farms (different characteristics)

• Construction costs formulated with Consorzio Bonifica Romagna Occidentale

• Scenarios:
  • “Size-rule”: a range of $q^t$
  • “n-rule”: the minimum number of agents required to have access to the RDP ($n \geq 1$, $n \geq 2$, $n \geq 3$)
  • share of the cost covered by the RDP ($\alpha = 30\%$, $\alpha = 50\%$, $\alpha = 70\%$)
Results – Characteristic function

- Increasing the threshold makes more and more difficult to obtain the financial support (bold numbers)
- Grand-coalition is more and more attractive (brackets)

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Results – n-Rule

- Shapley value (%)
  - 3 farms
  - Share of financial support: 70%

Farm A

Farm B

Farm C
**Results – size rule**

**Shapley value (%)**
- Different minimum participation threshold (size of reservoir)
- 3 farms
- Share of financial support: 70%

**Farm A: ≈10%**

**Farm B: ≈22%**

**Farm C: ≈67%**
Results – size rule

Shapley value (%)

- Farm C
- Different minimum participation threshold (size of reservoir)
- Share of financial support: 70%
Discussion

• Different solutions:
  • Shapley Value
  • Nash / Nash-Harsanyi
  • Nucleolus

• Limitations:
  • No public good:
    • SV assumes that the worth of a given coalition is not affected by the players outside the coalition
    • Further development to address this issue (Macho-Stadler et al., 2007)
  • Difficult to scale up
Conclusions

• Increasing interest from policy makers

• Literature not yet comprehensive

• Cooperative game theory worth further exploring
  • Conditionality rules are not neutral on benefit distributions
    – to take into account in policy formulation
  • Distribution matters in collective actions (Janssen et al 2011)
  • Coalition formation theory
Thanks!

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Results – Characteristic function

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Check super-additivity:

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Results – size rule

Shapley Value (%)
• Different minimum participation threshold (size of reservoir)
• 3 farms
• 3 different share of financial support

Farm A
- \( \alpha = 70\% \)
- \( \alpha = 50\% \)
- \( \alpha = 30\% \)

Farm B
- \( \alpha = 70\% \)
- \( \alpha = 50\% \)
- \( \alpha = 30\% \)

Farm C
- \( \alpha = 70\% \)
- \( \alpha = 50\% \)
- \( \alpha = 30\% \)
Discussion

• Increasing minimum participation threshold:
  • Increase attractiveness of cooperation
  • Asymmetric effect
  • Threshold on reservoir size: tend to empower bigger farms (up to a given level)
  • Threshold on number of participants: tend to empower smaller farms

• Extension/application to agglomeration incentives
  • Agglomeration payments vs agglomeration bonus
  • Cooperative game theory can address:
    • Spatial element
    • Social interactions