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Conditional Cooperation in Game Theory:

An Application to Reuse and Recycling Innovations

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Abstract

The aim of this note is to study waste reuse and recycling innovations in strategic environments. Due to the presence of widespread externalities, cooperation can help improve efficiency in equilibrium outcomes but requires the involvement of all players. Moreover, cooperation may differ when players' actions are strategic substitutes or strategic complements, as in the prisoner's dilemma and stag hunt games, respectively. Empirically, waste innovation practices for a sample of Italian firms are analysed with the aim of detecting the importance and nature of cooperation.

Keywords: waste reuse, waste recycling, strategic complementarity, strategic substitution

1 Introduction

Game theory can be applied to explore the interaction and decision-making process involved in waste reuse strategies, such as incentive mechanisms for promoting waste recycling practices within firms. Due to the presence of widespread externalities, cooperation can help improve efficiency in equilibrium outcomes but requires the involvement of all players. Indeed, gains can be higher if innovations are implemented by all firms. The evidence reported in [1] for Italian firms shows that it is difficult to obtain economic gains from circular economy-related innovations when taken in isolation. Moreover, equilibrium outcomes may differ when players' actions are strategic substitutes or strategic complements, as in the prisoner's dilemma and stag hunt games, respectively. This aspect is not trivial, since policy interventions should take into account the nature of interaction

schemes to foster the adoption of cooperative actions.
I describe the prisoner's dilemma game to highlight the nature of cooperation that is hardly implemented because of free riding at the individual level, and then I consider the stag hunt game for introducing the concept of conditional cooperation and the implied coordination failure. The empirical analysis, based on a sample of Italian firms, points to detecting the crucial features of the innovation game in order to assess whether firm investments in waste innovation are strategic substitutes or complements.

2 A waste innovation game

Consider a waste innovation game. Each player simultaneously chooses a strategy, and the combination of all players' strategies determines a payoff for each player. I consider player *i* against the set of other players –*i* in order to evaluate it as a two-player game. The choices in the game are referred to as actions. The set of pure actions available to player *i* is denoted A_i.

Assumption 1: A_i is finite and includes two possible actions, positive and null investment in waste innovation, respectively, denoted a_I and a_0: $A_i = \{a_I, a_0\}$

Definition 1: The set of pure action profiles is $A = A_i \times A_{-i}$, and game payoffs are given by a function u defined on A

$$u\colon\ A \to \mathcal{R}^2.$$

Definition 2: A payoff $v = u(a_i, a_{-i})$ for all possible combinations (a_i, a_{-i}) is *inefficient* if there exists another payoff v' with $v' \geq v$, for both players. The payoff v' weakly dominates v.

Definition 3: A payoff is *Pareto efficient* if it is not weakly dominated by any other feasible payoff.

Consider the normal form representation of the waste innovation game as reported in Table 1.

Table 1: Player *i* payoffs in the waste innovation game

		Other players	
		a_0	a_I
Player *i*	a_0	$u(a_0, a_0)$	$u(a_0, a_1)$
	a_I	$u(a_1, a_0)$	$u(a_1, a_1)$

The player *i* payoff is composed of two components: an *individual* gain that is determined by player *i* action and a *social* gain enjoyed by player *i* that is determined by other players' decisions. With regards to the individual component,

I denote with b the gain when player i action is a_0, and with g the gain when player i action is a_I. With reference to the social gain, I denote with β the player i gain when other players' action is a_0, and with γ the gain when players action is a_I.
The normal form representation of the waste innovation game reported in Table 2 assumes that the investment level is proportional to the individual and social gains.

Table 2: Player *i* payoffs in the waste innovation game

		Other players: a_0	Other players: a_I
Player *i*	a_0	$b+\beta$	$b+\gamma$
	a_I	$g+\beta$	$g+\gamma$

In the next sections, I show how individual gains affect the nature of the game and the nature of cooperation failure.

3 A free riding innovation game

As highlighted in [2] and [3], the prisoners' dilemma can be interpreted as a partnership game in which each player can either innovate (I) or not (0). With reference to the waste innovation game reported in table 2, I can show that a strictly dominant strategy of no innovation is obtained when the individual gain from innovating is smaller than the one from no innovation.

Definition 4: In the two player game, let a' and $a"$ be feasible actions for player i. Action a' is *strictly dominated* by action $a"$ if, for each possible combination of the other players' strategies, player i payoff from playing a' is strictly less than player i payoff from playing $a"$.

Statement 1: If player i individual gain is smaller when innovating, e.g. $g < b$, then the action a_0 strictly dominates the action a_I, whatever is other players' action.

Statement 2: If $g < b$, then the game equilibrium is (a_0, a_0), with an individual payoff of $u(a_0, a_0) = b + \beta$.

No innovation is a strictly dominant strategy, while higher payoffs are achieved if they both innovate. In an isolated interaction, there is no escape from this dilemma.

Statement 3: If $g < b$, then the game equilibrium (a_0, a_0) is Pareto inefficient.

In this case, actions are strategic substitutes, encompassing all situations with free riding. This is obtained if $u(a_I, a_I) < u(a_0, a_1)$ since $g < b$. In this view, waste innovation may entail costly experimentation and information collection, giving rise to potential free riding incentives.
Equilibrium outcome changes if the game is repeated. Suppose that the strategy of

each player is to invest in the first period and to continue to do so in every subsequent period as long as both players have previously invested, while stopping it in all other circumstances. Continued investment is optimal if the players are sufficiently patient, and hence future payoffs are sufficiently important.

4 A conditionally-cooperative innovation game

The framework where each player can either innovate (I) or not (0) can also be described as a coordination game, as suggested in [4]. With reference to the waste innovation game reported in table 2, I can show that no strictly dominant strategies arise when the individual gain from innovating is larger than the one from no innovation, and there are two Nash equilibria.

Statement 4: If player *i* individual gain is larger when innovating, e.g. $g > b$, then there is no dominant strategy.

Definition 5: In the two player game, the strategies (a_i^*, a_{-i}^*) are a Nash equilibrium if, for all players, a_i^* is player *i* best response to the strategy specified for the other players, a_{-i}^*.

Statement 5: If $g > b$, then there are two Nash equilibria: i) (a_0, a_0), with an individual payoff of $u(a_0, a_0) = b + \beta$; ii) (a_I, a_I), with an individual payoff of $u(a_I, a_I) = g + \gamma$.

In this case, actions are strategic complements. Strategic complements arise whenever the benefit that an individual obtains from innovation is greater as more of other players do the same. This corresponds to $u(a_I, a_I) > u(a_0, a_1)$ since $g > b$. In this view, waste innovation may entail individual benefits that increase the larger the set of all other players doing the same. Therefore, there is a risk associated with the conditional cooperation. This can be interpreted as a coordination failure issue. More precisely, one player's choice depends on his beliefs about what the other will choose.

5 Waste reuse and recycling innovation in Italian firms

Let us consider an application to waste innovation at the firm level. By specifying reduction and reuse strategies, firms can significantly decrease waste production and promote a more sustainable economy. By incorporating these strategies into their waste management practices, firms can not only reduce their environmental footprint but also reduce operational costs associated with waste disposal. The empirical analysis is based on firm-level data from a survey conducted in 2020 on a large sample of manufacturing Italian firms. See [1] for a detailed description of the methods and contents of the survey. To assess the strategic substitution or complementarity between waste innovation activities, the original dataset was combined with balance sheet data from the Bureau van Dijk AIDA dataset to end up with approximately 2700 observations, which are distributed in terms of size, geography, and sectors as the original sample.

Three performance variables are used to measure firm level payoffs, namely value added, profit and employment. The dataset reports information about positive investments to reduce, reuse and sell waste for each firm. For measuring other players' investment decisions, a variable indicates whether the firm believes the competitors had increased or decreased waste innovation investments in the previous two years. The econometric model specification is as follows:

$$y_i = \alpha_s + \alpha_r + \alpha_{size} + \beta'(INNO_i \# OTHER_i) + u_i \qquad (1)$$

where the dependent variable y_i is firm *i* performance measured by the value added va_i, the profit π_i or the employment level l_i (all in logs); α_s, α_r and α_{size} are sector, region, and size (in terms of employment groups) fixed effects, respectively to account for sector-specific, regional-specific and size-specific characteristics.

The variable $INNO_i$ is binary and takes value 1 if the firm increased investments in waste innovations in the reference period and 0 otherwise. The variable $OTHER_i$ is binary and takes value 1 if the firm believes that other firms increased investments in waste innovations in the reference period and 0 otherwise. The vector β includes the four coefficients relating to all possible combinations: (a_0, a_0), (a_0, a_I), (a_I, a_0), and (a_I, a_I). They are calculated as performance differentials with respect to (a_0, a_0) setting $\beta(a_0, a_0) = 0$ and after conditioning for sector, regional, and size differences. OLS estimates of the vector β in the waste innovation game are reported in Table 3.

Table 3: Estimated payoffs in the waste innovation game

Panel a): value added

Player *i*	Other players: a_0	Other players: a_I
a_0	0	-0.127***
a_I	-0.152	0.007

Panel b): profit

Player *i*	Other players: a_0	Other players: a_I
a_0	0	-0.390***
a_I	0.157	-0.147

Panel c): employment

Player *i*	Other players: a_0	Other players: a_I
a_0	0	-0.044
a_I	-0.011	0.024

Note: payoffs are calculated as deviations from the payoff calculated in the (a_0, a_0) combination; *,**, and *** indicate 10%, 5%, and 1% significance levels.

Tests of the following assumptions are also calculated:
i) $u(a_I, a_I) > u(a_I, a_0)$ and $u(a_0, a_I) > u(a_0, a_0)$ (T1);
ii) $u(a_I, a_I) > u(a_0, a_I)$ (T2).
Test T1 evaluates if player i social gain is larger if other players innovate, e.g., $\gamma > \beta$. Acceptance of T2 indicates a stag hunt game; otherwise, a prisoner's dilemma better describes waste innovation. In table 4, T1 and T2 test results are reported for model specification (1).

Two main facts are assessed from the estimated vector β. First, the assumption of a social gain of widespread waste innovation given by hypothesis T1 is not statistically confirmed. The decision of no waste innovation when other competitors do it implies a negative effect on value added and profit and a negligible effect on employment. Second, there is evidence of a stag hunt framework to describe the waste innovation decisions in a strategic environment. The coordination issue is a crucial feature to explain potential inefficiencies in the economic system since the hypothesis testing cannot reject the following inequality: $u(a_I, a_I) > u(a_0, a_1)$. The result is robust to the use of all measures of the firm's performance: value added, profit, and employment.

Table 4: Tests on social gains (T1) and conditional cooperation (T2)

	T1	p-value	*T2*	p-value
Value added	9.00	0.0111	0.1338	0
Profit	10.66	0.0049	0.2432	0
Employment	2.13	0.3451	0.0673	0

Note: T1 is a joint chi2 test on H0: $u(a_I, a_I) = u(a_I, a_0)$ and $u(a_0, a_I) = u(a_0, a_0)$; T2 is a z-test on H0: $u(a_I, a_I) = u(a_0, a_I)$.

5 Concluding remarks

Prioritizing waste reduction and reuse at the firm level is essential for fostering a more sustainable and responsible approach to business operations. In this note, I described how to implement and interpret estimation results and testing procedures for evaluating externalities in the waste innovation decisions using the lens of game theory. Both free riding and coordination failure could be at work in hampering the efficient level of investment. The evidence points to the preponderance of a coordination issue for a large sample of Italian firms.
There are some open questions that need to be investigated in the future. Firstly, whether different size classes give different patterns. Second, the analysis should be extended to other countries. Finally, future analysis should assess the policy implications of coordination failures in order to avoid the emergence of Pareto inefficient equilibrium outcomes.

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