Industrial Symbiotic Networks as Coordinated Games

Extended Abstract

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ABSTRACT

We present an approach for implementing a specific form of collaborative industrial practices—called Industrial Symbiotic Networks (ISNs)—as MC-Net cooperative games and address the so called ISN implementation problem. This is, the characteristics of ISNs may lead to inapplicability of *fair* and *stable* benefit allocation methods even if the collaboration is a collectively desired one. Inspired by realistic ISN scenarios and the literature on normative multi-agent systems, we consider *regulations* and normative socioeconomic *policies* as two elements that in combination with ISN games resolve the situation and result in the concept of *coordinated* ISNs.

KEYWORDS

Game Theory for Practical Applications; Industrial Symbiosis; MC-Net Cooperative Games; Normative Coordination; Policy and Regulation

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1 INTRODUCTION

Industrial Symbiotic Networks (ISNs) are collaborative networks of industries with the aim to reduce their materials and energy footprint by circulating reusable resources (e.g, physical waste material) among the network members [5, 11, 18]. Such a symbiosis leads to socioeconomic and environmental benefits for involved firms and the society. One barrier against stable ISN implementations is the lack of frameworks able to secure such networks against unfair and unstable allocation of obtainable benefits among the involved firms. In other words, even if economic benefits are foreseeable, lack of stability and/or fairness may lead to non-cooperative decisions and hence unimplementability of ISNs (ISN *implementation* problem). Reviewing recent contributions in the field of industrial symbiosis research, we encounter studies focusing on the interrelations between industrial enterprises [18] and the role of contracts in the process of ISN implementation [1]. We believe a missed element for shifting from *theoretical* ISN design to *practical* ISN implementation is to model, reason about, and support ISN decisions in a *dynamic* way—and not by using snapshot-based modeling frameworks.

This abstract reports on extending the game-theoretic approach of [19] with *regulative* rules and normative socioeconomic *policies*—following the successful line of work on normative multi-agent systems [3, 7, 17]. The extension provides a scalable solution to the ISN implementation problem and enables enforcing desired industrial collaborations in a fair and stable manner.

1.1 Research Questions

The following questions guide the design of a game-theoretic framework and its normative coordination mechanism that jointly facilitate the implementation of ISNs:

(1) ISN *Games*: How to define a game-theoretic basis for ISNs that both reflects their operational cost dynamics and allows the integration of normative rules?
(2) ISN *Coordination*: How to uniformly represent the regulatory dimension of ISNs using incentive rules and normative policies?
(3) *Coordinated* ISN *Games*: How to develop a framework that integrates normative coordination methods into ISN games to enable the fair and stable implementation of desirable ISNs—with respect to an established policy?

Dealing with ISNs' complex industrial context [20], an ideal ISN implementation platform would be tunable to specific industrial settings, scalable for implementing various ISN topologies, and would not require industries to sacrifice financially nor restrict their freedom in the market. Below, we present the overview of an approach for developing an ISN implementation framework with properties close to the ideal one.

2 OVERVIEW OF THE APPROACH

As discussed in [1, 19], the total obtainable cost reduction (as an economic benefit) and its allocation among involved firms are key drivers behind the stability of ISNs. For any set of agents involved in an ISN, this value—i.e., the obtainable cost reduction—characterizes the value of the set and hence can be seen as a basis for formulating ISNs as cooperative games. On the other hand, in realistic ISNs, the symbiotic practice takes place in presence of economic, social, and environmental *policies* and under *regulations* that aim to enforce the policies by nudging the behavior of agents towards desired ones. This is, while policies generally indicate whether an ISN is "good (bad, or neutral)", the regulations are a set of norms that—in case of agents' compliance—result in an acceptable spectrum of collective behaviors. We follow this normative perspective and aim to use normative coordination to guarantee the implementability of desirable ISNs—modeled as games—in a stable and fair manner. In the following subsections, we indicate how ISN games can be modeled and coordinated using regulatory incentive rules and normative socioeconomic policies.

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2.1 ISNs as Cooperative Games

In the game-theoretic representation of ISNs, the value of any set of agents S is defined [19] using the difference between the total cost that firms have to pay in case the ISN does not occur, i.e. costs to discharge wastes and to purchase traditional primary inputs (denoted by $T(S)$), and the total cost that firms have to pay collectively in case the ISN is realized, i.e. costs for recycling and treatment, for transporting resources among firms, and transaction costs (denoted by $O(S)$). Formally, the ISN among agents in a non-empty finite set of agents N is a normalized superadditive cooperative game (N, v) where for $S \subseteq N$, $v(S)$ is equal to $T(S) - O(S)$ if $|S| > 1$, and 0 otherwise.

Benefit sharing is crucial in the process of ISN implementation, mainly because of stability and fairness concerns. Roughly speaking, firms are rational agents that defect unbeneficial collaborations (instability) and mostly tend to reject relations in which benefits are not shared according to contributions (unfairness). Focusing on the Core and Shapley allocations [12, 16]—as standard methods that characterize stability and fairness—these solution concepts appear to be applicable in a specific class of ISNs but are not generally scalable for value allocation in the implementation phase of ISNs. In particular, relying on the balancedness of two-person ISN games, denoted by ISN_Λ, we can show that any ISN_Λ is implementable in a fair and stable manner. However, in larger games—as balancedness does not hold necessarily—the core of the game may be empty which in turn avoids an ISN implementation that is reasonable for all the involved firms. So, even if a symbiosis could result in collective benefits, it may not last due to instable or unfair implementations. A natural response which is in-line with realistic practices is to employ monetary incentives as a means of normative coordination—to guarantee the implementability of "desired" ISNs. To allow a smooth integration with normative rules, we transform ISN games into *basic MC-Nets*[1] through the following steps: let (N, v) be an arbitrary ISN game, $S_{\geq 2} = \{S \subseteq N : |S| \geq 2\}$ be the set of all groups with two or more members where $K = |S_{\geq 2}|$ denotes its cardinality. We start with an empty set of MC-Net rules. Then for all groups $S_i \in S_{\geq 2}$, for $i = 1$ to K, we add a rule $\{\rho_i : (S_i, N \setminus S_i) \mapsto v_i = T(S_i) - O(S_i)\}$ to the MC-Net.

2.2 Normative Coordination of ISNs

Following [7, 17], we see that norms can be employed as game transformations to bring about more desirable outcomes in ISN games. For this account, given the economic, environmental, and social dimensions and with respect to potential socioeconomic consequences, ISNs can be partitioned in three classes by a normative socioeconomic policy function $\wp : 2^N \mapsto \{p^+, p^\circ, p^-\}$, where N is a finite set of firms. Moreover, p^+, p°, and p^- are labels—assigned by a third-party authority—indicating whether an ISN is promoted, permitted, or prohibited, respectively.

The rationale behind introducing policies is mainly to make sure that the set of promoted ISNs are implementable in a fair and stable manner while prohibited ones are instable. To ensure this, in real ISN practices, the regulatory agent introduces monetary incentives, i.e., ascribes subsidies to promoted and taxes to prohibited collaborations. We follow this practice and employ a set of rules to ensure/avoid the implementability of desired/undesired ISNs by allocating incentives[2]. Such a set of incentive rules can be represented by an MC-Net $\mathfrak{R} = \{\rho_i : (\mathcal{P}_i, \mathcal{N}_i) \mapsto \iota_i\}_{i \in K}$ in which K is the set of rule indices. Then, the incentive value for $S \subseteq N$, is defined as $\iota(S) \coloneqq \sum_{i \in \mathfrak{I}(S)} \iota_i$ where $\mathfrak{I}(S)$ denotes the set of rule indices that are applicable to S. It is provable that for any ISN game there exists a set of incentive rules to guarantee its implementability.

2.3 Coordinated ISN Games

Having policies and regulations, we integrate them into ISN games and introduce the concept of *Coordinated* ISN*s* ($C-$ISNs). Formally, let G be an ISN and $\mathfrak{R}$ be a set of regulatory incentive rules, both as MC-Nets among agents in N. Moreover, for each group $S \subseteq N$, let $v(S)$ and $\iota(S)$ denote the value of S in G and the incentive value of S in $\mathfrak{R}$, respectively. We say the Coordinated ISN Game ($C-$ISN) among agents in N is a cooperative game (N, c) where for each group S, we have that $c(S) = v(S) + \iota(S)$.

It can be observed that employing such incentive rules is effective for enforcing socioeconomic policies. In particular, we have that for any promoted ISN game, under a policy $\wp$, there exist an implementable $C-$ISN game. Analogously, similar properties hold while *avoiding* prohibited ISNs or *allowing* permitted ones. The presented approach for incentivizing ISNs is advisable when the policy-maker is aiming to ensure the implementability of a promoted ISN in an ad-hoc way. In other words, an $\mathfrak{R}$ that ensures the implementability of a promoted ISN G_1 may ruin the implementability of another promoted ISN G_2. To avoid this, the set of collaborations that a policy $\wp$ marks as promoted should be mutually exclusive. Accordingly, we have the desired result that the mutual exclusivity condition is sufficient for ensuring the implementability of *all* the ISNs among $\wp$-promoted groups in a fair and stable manner.

3 CONCLUDING REMARKS

The details of the components for developing the ISN implementation framework—rooted in cooperative games and coordinated with normative rules—consist of algorithms for generating incentive rules and policy properties to ensure the implementability of promoted ISNs. We plan to explore the possibility of having multiple policies and tools for policy option analysis [13] in ISNs. Then, possible regulation conflicts can be resolved using prioritized rule sets (inspired by formal argumentation theory [9, 15]). We also aim to focus on administration of ISNs by modeling them as normative multi-agent organizations [4, 20] and relying on norm-aware frameworks [2, 6] that enable monitoring organizational behaviors.

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[1] A basic MC-Net represents a game in N as a set of rules $\{\rho_i : (\mathcal{P}_i, \mathcal{N}_i) \mapsto v_i\}_{i \in K}$, where $\mathcal{P}_i \subseteq N$, $\mathcal{N}_i \subset N$, $\mathcal{P}_i \cap \mathcal{N}_i = \emptyset$, $v_i \in \mathbb{R} \setminus \{0\}$, and K is the set of rule indices. For a group $S \subseteq N$, a rule ρ_i is applicable if $\mathcal{P}_i \subseteq S$ and $\mathcal{N}_i \cap S = \emptyset$. Then $v(S)$ will be equal to $\sum_{i \in \Pi(S)} v_i$ where $\Pi(S)$ denote the set of rule indices that are applicable to S. This rule-based representation allows natural integration with rule-based coordination methods and results in relatively low complexity for computing allocation methods such as the Shapley value [8, 10].

[2] See [14, 21] for similar approaches on incentivizing cooperative games.

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