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Innovation Incentives in Enterprise Networks: A Game Theoretic Approach

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Abstract

This paper studies the determination of innovation incentives in enterprise networks through an application of game theoretic modelling. Here, game theory provides tools for the formal analysis of situations where multiple decision-makers may have partially conflicting interests, but cooperation between them is allowed. An example from the boat-building industry is presented to illustrate the relevance of innovation incentives in enterprise networks. Specifically, three different equilibrium concepts are applied to determine innovation incentives under different circumstances. The proposed model helps award innovations that improve the efficiency of the network. In addition, the efficiency-improving arrangements can be implemented so that none of the network companies has to suffer. Consequently, the enterprise network becomes innovative and the network companies need not fear their own losses when the efficiency-improving arrangements are implemented. The model also helps share the surplus utility gained through the innovation among the companies of the network.

Keywords: network economy, enterprise networks, game theory, innovation management, demand supply chain management

1 Introduction

The need for models and practises for inter-firm relationships has been brought out by various authors. In a recent paper, Cousins and Spekman (2003) suggest that the trend of increasing collaboration in supplier networks calls for practises that encourage the suppliers to innovate. The same message can be found in, e.g. Gertsen (2003), Lei (2003), Purdon (1996), Rogers (1996), Cutler (1991).

However, the literature concerning innovation incentive mechanisms is mostly concentrated either on the governmental level (Conceição et al. 2003, Kuhlmann and Edler 2003, Jaffe 2000) or on the intra-firm level (Bester and Petrakis 2004, Nerkar et al. 1996, Leptien 1995). This paper takes a new viewpoint by studying process-innovation incentives in *company networks*. By process-innovation incentives we denote the guarantee of a win-win situation among the network companies, whenever the total efficiency of the network increases. The study is based on the supplier network of a Finnish sailing-yacht builder.

The main contribution of this paper is the construction of mechanisms that encourage suppliers to process innovations. The mechanisms are to be implemented as *ex-ante* contracts. We take a game theory approach in order to present three strategies for utility sharing, which encourages suppliers to innovations. Moreover, we shall show that a win-win situation is possible whenever a process innovation is implemented.

Earlier, game theoretic utility sharing (bargaining[1]) has been applied, for instance, to determine aircraft landing fees, to study the bankruptcy problem (Casas-Méndez et al. 2003, Thomson 2003), or to allocate income among service providers (Ginsburgh and Zang 2003). We thus connect two traditionally separately studied fields of research, namely, innovation incentives and game theoretic bargaining.

[1]For game theoretic foundations of bargaining, see e.g. Nash (1950), Shapley (1953), Kalai and Smorodinsky (1975).

The structure of the paper is as follows. Section 2 presents a game theoretic model by which we show that the possibility of a win-win situation exists whenever the efficiency of the network is improved. Section 3 presents three different bargaining solutions that can be applied as process-innovation incentives for suppliers. In Section 4 we illustrate the use of the model with a numerical example. Section 5 summarises the results and conclusions of the paper.

2 Process-Innovation Incentives for Supplier Networks

2.1 Example of a Process Innovation

This section clarifies what the term *process innovation* means in this paper. First, the following example illustrates the case:

Example 1 (Installing HPAC in boat building) *The client of this example is a Finnish sailing-yacht manufacturer, who has recently launched the production of a new type of boat. The client has accumulated a network of suppliers, each working on one component of the new boat. Among others, there are two suppliers pertinent to this example: a hull manufacturer and a heating, plumbing and air-conditioning (HPAC) installer.*

In the construction of the very first boats, the HPAC installer himself drilled holes for the pipelines into the ready-made hull. Drilling the holes was time-consuming, since the drillman had to work in a constricted space and in uncomfortable positions. The striking change was to transfer the drilling of the holes from the HPAC installer to the hull construction, where the work could be done before the hull was assembled. This transfer of work reduced the total costs of the manufacturing process, since the work-load related to the drilling was reduced significantly.

More generally, consider a company network that consists of a *client* and several *suppliers*. The network forms a supply chain in which each of the companies carries out a specified task, which is part of the manufacturing of a final product. The client pays the suppliers for their work. In this environment, a process innovation is an idea that leads to improvement in the efficiency of the manufacturing process. In practise, this may occur in several ways, e.g. as cost reduction or improvement in quality. In the following sections, we shall generalise this case in the concepts of game theory.

2.2 Modelling the Process Innovation as Game

When studying process innovations in enterprise networks, we motivate the particular utilisation of *game theoretic* concepts as follows. The problem of cases similar to Example 1 is that the work-load of the suppliers change. This raises the need to change the supplier payments. First, the supplier whose work-load increases (the hull constructor of Example 1) probably claims for a compensation. Second, the natural way to finance this compensation is to reduce the payment to the supplier whose work-load decreases (the HPAC installer). Third, the client also wants a share of the cost savings in order to gain competitive advantage against competitors' improvements in their performance. In addition, in order to encourage the network to continuous innovation, the individual companies of the network should be guaranteed at least a no-loss situation whenever a process innovation is implemented. Otherwise, if there is a fear of own losses, the network companies might be unwilling to bring out ideas that could improve the efficiency of the network as a whole. This dilemma is referred to as the *moral hazard*.

The same situation arises in numerous cases related to inter-firm relationships: despite of the network's common goal of joint gains, the objectives of individual firms are partly conflicting. Such circumstances are often analysed by the means of game theory (see, e.g. Nalebuff and Brandenburger 1996).

Our approach to the problem is *ex-ante* contracting. The idea is that, if all parties can be guaranteed an increase in benefit whenever a process innovation is implemented, then the companies have the incentive to innovate. In the following, we shall construct a game theoretic model that captures the described case.

The players of the game are $N = \{1, \dots, n\}$, where indices $N_s = \{1, \dots, n-1\}$ denote the suppliers and n is the client. In the *status quo*, a player $i \in N_s$ performs work w_i, for which he receives a positive payment p_i from n. Hence, *the profit* for a player $i \in N_s$ is

$$\text{profit}_i = p_i - v_i, \tag{1}$$

where v_i is i's non-negative costs for the activity w_i (consisting of labour costs, material costs, etc.). If the supplier i's work load w_i changes by, say Δw_i, then we let Δv_i denote the corresponding *change in i's costs*. Furthermore, let Δp_i denote the change in i's fixed payment due to the change in work load. The *change in i's profit* is then

$$\pi_i(\Delta p_i) = \Delta p_i - \Delta v_i, \quad \forall\, i \in N_s. \tag{2}$$

Since player n makes the payments Δp_i to players $1, \dots, n-1$, the change in n's profit is

$$\pi_n(\mathbf{\Delta p}) = -\sum_{i=1}^{n-1} \Delta p_i, \tag{3}$$

where $\mathbf{\Delta p}$ denotes the vector $(\Delta p_1 \ \dots \ \Delta p_{n-1})$. We shall use (2) as *the utility function for players* $i \in N_s$ and (3) as *the utility function for player* n. Hence, in the *status quo* all the players' utilities are equal to zero.

It is noteworthy, that the total utility derived from the process innovation is

$$\pi_{\max} = -\sum_{i=1}^{n-1} \Delta v_i. \tag{4}$$

Hence, if the total change in costs is negative, then a win-win situation is created. In the following section, we shall present several ways to share the surplus utility.

3 Bargaining Solutions as Innovation Incentives

3.1 Egalitarian Solution for the *Ex-ante* Contracting

This section presents one possible formulation for the utility-sharing rule Δp. Let $N_w \subseteq N_s$ be the set of suppliers whose costs change due to the process innovation, i.e. $N_w = \{i \in N_s \mid \Delta w_i \neq 0\}$. Let $n_w = |N_w|$ be the cardinality of N_w. We construct Δp on the following conditions:

$$\pi_n = \pi_i, \quad \forall \ i \in N_w \tag{5}$$

$$\pi_i = 0, \quad \forall \ i \in N_s \setminus N_w. \tag{6}$$

In other words, condition (5) says that the suppliers involved in the rationalisation $(i \in N_w)$ and the client (n) benefit equally. Condition (6) means that the other suppliers' payments stay unchanged. The conditions (5) and (6) imply the following rule Δp:

$$\Delta p_i = \begin{cases} \Delta v_i + \dfrac{\pi_{\max}}{n_w + 1}, & \forall \ i \in N_w \\ 0, & \forall \ i \notin N_w. \end{cases} \tag{7}$$

That is, the suppliers involved in the rationalisation are paid the amount according to their change in costs plus a share of the surplus utility (4). This allocation gives each supplier $i \in N_w$ and the client n an equal payoff of

$$\pi_i^* = \frac{\pi_{\max}}{n_w + 1}, \quad \forall \ i \in N_w \cup \{n\}. \tag{8}$$

3.2 Use of Threats in Contract Negotiation

It may be fruitful to examine what happens if the suggested alteration in prices is not commonly accepted. Therefore, assume that each player $i \in N$ has an additional possible strategy, threat τ_i, which is the termination of the partnership. If a player executes the threat strategy, the game ends in disagreement. The payoffs to the players in disagreement are denoted by $\tau_1, \ldots, \tau_n$. Since the termination of partnership normally causes additional transaction costs to each party, the τ's are usually negative.

The share of utility in the threat game can be defined by the unique strongly-efficient vector $\boldsymbol{\pi} \in F$ that maximises the Nash product (Nash 1953):

$$\boldsymbol{\pi}^* = \arg\max_{\boldsymbol{\pi}} \prod_{i \in N_w \cup \{n\}} (\pi_i - \tau_i). \tag{9}$$

The maximisation of (9) is equivalent to solving the following conditions

$$\pi_i - \tau_i = \pi_j - \tau_j \qquad \forall \; i, j \in N_w \cup \{n\} \tag{10}$$

$$\sum_{i \in N_w \cup \{n\}} \pi_i \overset{(4)}{=} - \sum_{i \in N_w} \Delta v_i. \tag{11}$$

Conditions (10) and (11) form a linear system of $|N_w| + 1$ equations containing the same number of unknown variables (the π_i's). Thus, solving the system for π_i's defines vector $\boldsymbol{\pi}$ uniquely.The utility-sharing rule Δp can then be calculated from (2):

$$\Delta p_i(\boldsymbol{\tau}) = \pi_i(\boldsymbol{\tau}) + \Delta v_i, \tag{12}$$

where $\boldsymbol{\tau}$ denotes the vector that consists of τ_i's such that $i \in N_w \cup \{n\}$.

3.3 Harsanyi's Modified Shapley Value in Contract Negotiation

In Section 2.2, the game model has been constructed for n players without considering *coalitions*. This section presents one possible solution that takes account of coalition formation. For each $i \in N_w, j \in N$, let $\tau_j(i)$ denote the utility (or cost) to player j if the contract between i and n is terminated. For convenience, we write $\tau_i(i) = \tau_i, \; \forall \; i \in N_w$. We assume, that there is always at least one supplier $i \in N_w$ such that $\tau_i < 0$. That is, if i's contract with the client n is terminated, then i suffers a loss in utility. This assumption eliminates the possibility that all the suppliers ally against the client.

A coalitional game is normally defined by its characteristic function $\nu(S)$. Originally, von Neumann and Morgenstern (1944) defined $\nu(S)$ by a *minimax* representation. We shall, however, use the definition presented by Harsanyi (1963). The idea is that, instead of maximising merely the total utility, a coalition should maximise the *difference between its own total utility and the competitors' total utility*. Thus, the coalitions' optimal strategies become

$$c_S^* = \arg\max_{c_S} \left(\sum_{i \in S} \pi_i(c_S, c_{N \setminus S}^*) - \sum_{j \in N \setminus S} \pi_j(c_S, c_{N \setminus S}^*) \right) \tag{13}$$

$$c_{N \setminus S}^* = \arg\min_{c_{N \setminus S}} \left(\sum_{i \in S} \pi_i(c_S^*, c_{N \setminus S}) - \sum_{j \in N \setminus S} \pi_j(c_S^*, c_{N \setminus S}) \right) . \tag{14}$$

The characteristic function is defined as

$$\nu(S) = \sum_{i \in S} \pi_i(c_S^*, c_{N \setminus S}^*), \tag{15}$$

where the strategies $(c_S^*, c_{N \setminus S}^*)$ are obtained from (13) and (14).

An elaborate means of finding an outcome for n-player bargaining is the *Shapley value*, which was introduced by Shapley (1953). The Shapley value for player i of a coalitional game ν is

$$\varphi_i(\nu) = \sum_{S \subseteq N \setminus \{i\}} \frac{|S|! \, (|N| - |S| - 1)!}{|N|!} \left(\nu(S \cup \{i\}) - \nu(S) \right) , \tag{16}$$

where $\nu(X)$ is the characteristic function (the worth) of coalition X. As has been discussed earlier, the possibility of using threats is an essential part of the game. For this purpose, Harsanyi (1963) presents a *modified Shapley value*, which is calculated from the original formula (16) but with the characteristic function defined in (13)-(15).

In our process-innovation game, the modified Shapley values for the suppliers $(1, \ldots, n-1)$ and the client (n) are

$$\begin{aligned}
\varphi_i &= \frac{\pi_{\max}}{|N_w|+1} - \frac{\tau_n(i)}{2} + \frac{\tau_i}{2}, && i \in N_w && \text{(a)} \\
\varphi_j &= 0, && j \in N_s \setminus N_w. && \text{(b)} \\
\varphi_n &= \frac{\pi_{\max}}{|N_w|+1} + \frac{\sum_{i\in W_a} \tau_n(i)}{2} - \frac{\sum_{i\in W_a} \tau_i}{2}. && && \text{(c)}
\end{aligned} \tag{17}$$

It is straightforward to verify that the players' modified Shapley values (17) sum up to the total available utility:

$$\sum_{i\in N_w} \varphi_i + \sum_{j\in N_s\setminus N_w} \varphi_j + \varphi_n = \pi_{\max}, \tag{18}$$

that is, the allocation $\mathbf{\Phi} = (\varphi_1 \ \ldots \ \varphi_n)$ is efficient.

The utility-sharing rule Δp according to the modified Shapley value is obtained by replacing π_i in (2) by φ_i:

$$\Delta p_i = \Delta v_i + \frac{\pi_{\max}}{|N_w|+1} - \frac{\tau_n(i)}{2} + \frac{\tau_i}{2}, \quad \forall\, i \in N_s. \tag{19}$$

The rule (19) takes account of the fact that the suppliers with $\tau_i < 0$ are more dependent on the client (n) than the other suppliers. Hence, it is reasonable that the incentive for the former is lower than that for the latter.

4 Numerical Application of Innovation Incentives

This section applies the results of Section 3 to a network that consists of two suppliers and a client (Figure 1). Let us denote the two suppliers by indices 1 and 2 and the client by index 3. The network manufactures a product, which is being sold to end-customers by the client. The suppliers both have a vital role in the network, supplying the client with certain components of the final product, for which the client pays the suppliers a fixed payment per each component.

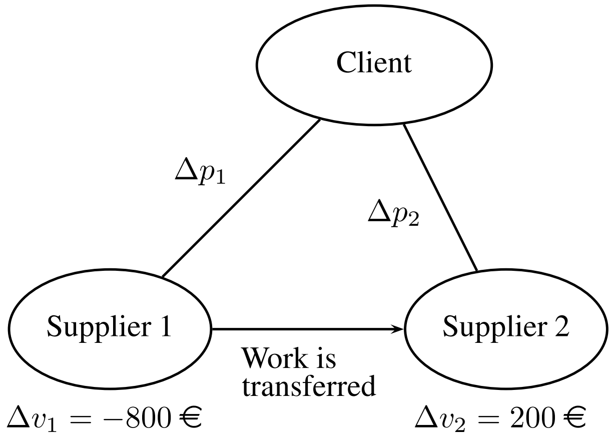

Figure 1: Enterprise Network of the Example

Among other duties, supplier 1 carries out a job that, according to cost accounting, involves the expenses of 800 € per each final product manufactured. In negotiations within the network, it has become clear that supplier 2 could perform the same job with costs of only 200 €. That is, by transferring the work from supplier 1 to supplier 2 the network could save up to 600 € per final product. This rationalisation manoeuvre, however, necessitates a change in the fixed payments (Δp_i's) that the client effects to the suppliers. By this simple example, we shall illustrate the calculation of the three different payment reallocations, which are suggested in the sections 3.1-3.3.

Following the notation introduced in Section 2.2, we have three companies $N = \{1, 2, 3\}$ and the set of suppliers that are involved in the process innovation are $N_w = \{1, 2\}$. The changes in the suppliers' costs are $\Delta v_1 = -800$ € and $\Delta v_2 = 200$ €. Thus, the total benefit of the work transfer is (from 4)

$$\pi_{\max} = -\sum_{i \in N_w} \Delta v_i = -(-800 + 200)\text{ €} = 600\text{ €}.$$

To illustrate how threats can affect the reallocation of the payments, let us assume that the client can terminate the contract with the supplier 1. Assume further, that the client can easily find a

Table 1: Comparison of the Different Solution Concepts

Company	π^* (€)	π^{T} (€)	π^{S} (€)
1	200	100	125
2	200	250	200
3	200	250	275

substitute supplier, whereas for the supplier 1 it is difficult to find a new customer. Hence, if the contract is terminated, the losses to supplier 1 are valued at $\tau_1 = -150$ €, proportioned to the income of supplier 1 from the present client. The client would not suffer any losses from the termination of the contract ($\tau_3(1) = 0$ €). Under these circumstances, the client possesses a credible threat against supplier 1.

Table 1 shows how the utility is shared among the companies using the three solution concepts presented in Section 3. In *the egalitarian solution* π^*, the supplier 1, whose work load decreases, incurs a fall of $\Delta p_1 = -600$ € in the fixed payment from the client. Supplier 2, for one, receives a supplement of $\Delta p_2 = 400$ € for the increased work load. Thereby, in the egalitarian solution, all the participants' utilities are equal (200 €), exactly as should be by (5).

According to *the relative threats approach* π^{T}, the changes in the payments to suppliers become $\Delta p_1 = -700$ € and $\Delta p_2 = 450$ €. That is to say, in consequence of supplier 1's dependence on the client, supplier 1 loses 100 € in comparison with the egalitarian solution. The surplus 100 € is divided up evenly among the client and supplier 2.

In determining the solution according to the *modified Shapley value* π^{S}, we assume the same interdependencies inside the network as in the previous solution. That is, the client possesses a credible threat $\tau_1 = -150$ € against supplier 1. The changes in payments are $\Delta p_1 = -675$ € and $\Delta p_2 = 400$ €. Thus, the only participant who benefits from the weakness of supplier 1 is the one who has the potency to execute the threat, i.e. the client.

5 Summary and Conclusions

In this paper, we have introduced a game that models the creation of process innovations in enterprise networks. Often, when a process innovation is implemented, the costs of some network companies increase, whereas the costs of some other companies in the network reduce. The first criterion for the rationalisation is that the *total reduction in costs is greater than the total increase in costs*. The other criterion is that each of the network companies are better off after the rationalisation has been carried out. That is, the *companies whose costs increase need a compensation payment* in order to accept the implementation of the rationalisation manoeuvre.

The main idea of our model is that when the network companies know that they will be compensated in the case of a rationalisation manoeuvre, then the companies are willing to implement and suggest efficiency-improving ideas. Hence, the principles of compensation should be implemented as *ex-ante* contracts.

The utility sharing is studied in three different cases. First, it is assumed that the companies do not threaten each other, nor will they ally against each other. The second case allows threats between the firms. The third case is the most general, allowing threats and coalitions inside the enterprise network. In each case, a win-win situation among the members of the network can be guaranteed, whenever a process innovation is implemented.

This paper has brought a new perspective to the discussion on network innovations by applying game theory to the determining of innovation incentives. Topics for further research could be, for instance, product-innovation incentives in networks, or the preconditions for creating disruptive innovations in networks.

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