European Journal of Operational Research 234 (2014) 763–773

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Decision Support

Surplus division and investment incentives in supply chains: A biform-game analysis

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ARTICLE INFO

Article history:
Received 6 May 2013
Accepted 21 September 2013
Available online 7 October 2013

Keywords:
Supply chain management
Shapley value
Biform game
Underinvestment problem
Incentive system
Subsidies

ABSTRACT

In this paper, we use a biform-game approach for analyzing the impact of surplus division in supply chains on investment incentives. In the first stage of the game, firms decide non-cooperatively on investments. In the second stage, the surplus is shared according to the Shapley value. We find that all firms have inefficiently low investment incentives which, however, depend on their position in the supply chain. Cross-subsidies for investment costs can mitigate, but not eliminate the underinvestment problem. Vertical integration between at least some firms.yields efficient investments, but may nevertheless reduce the aggregated payoff of the firms. We show how the size of our effects depends on the structure of the supply chain and the efficiency of the investment technology. Various extensions demonstrate that our results are qualitatively robust.

1. Introduction

Effective supply chain management can yield various benefits such as lower inventories by avoiding the well-known Bullwhip effect (Forrester, 1958; Lee et al., 1997; Größler et al., 2008). Consequently, supply chains are often defined as agreements for maximizing the joint surplus of the participating firms (Chopra and Meindl, 2001;Mentzer et al., 2001). In this paper, we analyze how the surplus division in supply chains influences the incentives for investments which improve the supply chain's efficiency. As we find that investment incentives are inefficiently low, we discuss two possibilities to reduce this inefficiency, subsidies for the investments of other firms and costly binding contracts on investment levels.

Recently, the so-called biform-approach which combines elements from non-cooperative and cooperative game theory (Brandenburger and Stuart, 2007) has been applied to several problems in supply chain management (see the literature review in Section 2).[1] We follow this approach by distinguishing two stages in the process of establishing a supply chain project. In the first stage, firms can make investments which increase the efficiency of the supply chain. For instance, a manufacturer might improve its IT system which saves costs for coordinating the information flow with a supplier and a wholesaler, or a retailer may install an online order-entry system for the end consumer which improves the value of the supply chain. As these investments often take place before an agreement on the supply chain level is reached, we assume that they are made *non-cooperatively*.

In the second stage, the supply chain project is conducted. For this stage, we apply *cooperative* game theory and assume that the surplus is shared according to the most widely accepted cooperative solution concept for more than two players, the Shapley value (Shapley, 1953). As a motivating example, we use the simplest straight supply chain often observed in practice which consists of a supplier, a manufacturer, a wholesaler and a retailer. Because of their positions in the supply chain, we refer to the manufacturer and the wholesaler as center firms, and to the supplier and the retailer as brink firms. We find that the Shapley value assigns less of the surplus to brink firms, and we show how this reduces their investment incentives in the first stage of the game. We believe that biform games are appropriate for our research question on the impact of surplus division on investment incentives as firms may often reach (approximately) efficient solutions *after* supply chains have been formed (ex post-perspective). Thus, cooperative game theory can be applied for the second stage of the game. By contrast, coordinating on ex ante-investments which maximize the overall future value of the supply chain is more difficult due to transaction costs (Williamson, 1975).[2] Therefore, non-cooperative game theory is adequate for the first stage.

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[1] In their paper on biform-games, Brandenburger and Stuart (2007) use the core rather than the Shapley value as solution concept for the cooperative part of their game. We use the term "biform game" more generally for all games combining non-cooperative and cooperative stages.

[2] Most prominently, biform games are used in incomplete contract theory (Hart and Moore, 1999; Tirole, 1999). Incomplete contract theory assumes that binding contracts for investments are infeasible, but that the parties agree on the efficient solution and share the surplus cooperatively after the investments have been made.

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http://dx.doi.org/10.1016/j.ejor.2013.09.039

Our main findings can be summarized as follows: *First* and as already mentioned, we find that the surplus will be split asymmetrically among the firms involved, with brink firms getting less of the surplus. *Second*, we show that not only brink firms but all firms will make inefficiently low investments where our efficiency benchmarks are the investment levels which maximize the joint surplus of the participating firms. This result can be attributed to non-internalized positive externalities on other firms and is qualitatively robust with respect to the specification of the investment technology.

Given this underinvestment result, we analyze wehther firms can increase their investment incentives by subsidies or vertical integration. For subsidies, we add an additional non-cooperative stage to the game where each firm can subsidize the investments of other firms. For instance, a wholesaler who knows that he might benefit from a manufacturer's improved IT system in a supply chain may cover part of the cost of the new system.[3] Our *third* result is that subsidies mitigate, but do not fully eliminate the underinvestment problem.

We then discuss vertical integration by assuming that any two directly linked firms can integrate at some costs. Integration improves investment incentives as it eliminates the externality problem between any two integrating firms. Strikingly, however, incentives for vertical integration are, compared to our efficiency benchmark which is the aggregated payoff of all firms, excessively high whenever the value of the supply chain consisting of all firms is relatively low compared to the value of smaller supply chains. We provide an intuition for our finding which shows that the result is robust with respect to different ways of modeling the supply chain.

The assumptions of our basic model allow a streamlined analysis, but some of them are restrictive from a practical point of view. We hence discuss several extensions with respect to the investment technologies and the value of different coalitions, and we show that our results are qualitatively robust.

The remainder of the paper is organized as follows: Section 2 relates to the literature. Section 3 presents the model. Section 4 applies the Shapley value as a solution concept for surplus division, and derives investment incentives. Section 5 discusses subsidies as potential remedies for the underinvestment problem. Section 6 proceeds to vertical integration. Section 7 discusses the robustness of our results with respect to various extensions. We conclude in Section 8.

2. Related literature

In recent years, game theory has gained importance for analyzing effective supply chain management. Many papers apply either non-cooperative (Cachon and Netessine, 2004;Nagarajan and Sošić, 2008) or cooperative solution concepts (Leng and Parlar, 2005). For cooperative solution concepts, the Shapley value dominates. Raghunathan (2003) uses the Shapley value for analyzing information sharing among a manufacturer and several retailers in a supply chain. As in our paper, he shows that the role in the supply chain influences the surplus division and the incentives of forming supply chains. Accordingly, Leng and Parlar (2009) analyze the division of cost savings from sharing demand information. They compare different solution concepts of cooperative game theory, including the Shapley value. Rosenthal (2008) uses the Shapley value to determine transfer prices for intermediate products in a vertically integrated supply chain. Kemahlioğlu-Ziya and Bartholdi (2011) use the Shapley value to allocate the expected excess profit generated by inventory pooling in supply chains among a supplier and his retailers. All of these papers, however, do not extend to incentive problems which requires stages where decisions are taken non-cooperatively.

As mentioned in the introduction, our approach is most closely related to biform games which apply cooperative and non-cooperative solution concepts in different stages of the game. Anupindi et al. (2001) use such a biform-approach for a game with multiple retailers. First, each retailer decides non-cooperatively on his stocking decision. Then, the retailers observe demand and decide cooperatively on how much inventory to transship among locations in order to better match supply and demand. For this decision and for the profit allocation, they use the core (Gillies, 1959) as solution concept. Contrary to this, we apply the Shapley value, and we introduce assumptions ensuring that the Shapley value is in the core.

By extending the approach of Anupindi et al. (2001),Granot and Sošić (2003) allow retailers to hold back the residual inventory. Their model consists of three stages, the inventory procurement which is done non-cooperatively, the decision about how much inventory to share with others, and the transshipment stage (cooperative stages). The non-cooperative stage corresponds to the investment decision in the first stage of our model, whereby the cooperative stage equals the division of surplus in the second step of our model.

Taylor and Plambeck (2007a), Taylor and Plambeck, 2007b analyze games between two firms who might pool their capacity and investments to maximize the overall value of the supply chain. As in our model, firms first decide non-cooperatively on their investments, and then bargain cooperatively over the division of the market and the respective profits. Contrary to this paper, we focus explicitly on the supply chain structure taking the respective position of firms into account so that the impact of the position on investment incentives can be analyzed. Chatain and Zemsky (2007) use a biform game for considering the advantages of coordinating suppliers, the optimal level of buyer power, and the desirability of subsidizing suppliers.

Leng and Zhu (2009) discuss subsidies as side-payments which are potentially required when allocating the surplus. They provide a comprehensive literature review on different types of side payments. However, these side payments are transfers in supply chains for reaching the grand coalition, and as such are by definition of cooperative game theory assumed to be always feasible. This is different to the subsidies in our paper which are non-cooperative payments taken for influencing the investment decisions before the supply chain formation.

More generally, our paper is related to biform games analyzing the impact of the surplus division on business decisions such as investments, advertising or mergers. The common feature of the literature is that firms first decide on how to "shape" the competetive environment which then defines the playing field for cooperative bargaining. Biform-games allow to account for two motives of business strategies, increasing efficiency on the one hand, and improving the own bargaining position on the other hand (see Brandenburger and Stuart, 2007).[4]

While we assume that the surplus is shared according to the Shapley value, some of these papers including Inderst and Wey (2003) and DeFontenay and Gans (2005) define a non-cooperative bargaining structure which yields the Shapley division as a Nash Equilibrium of the non-cooperative bargaining game. As we do in Section 6, both papers compare private and social incentives for integration. While Inderst and Wey (2003) discuss incentives for

[3] Of course, such an agreement implies some kind of enforceable contract, but is still less challenging than contracting on investment levels.

[4] In our analysis of the incentives for vertical integration, these two motives can clearly be disentangled and determine whether, from an overall efficiency perspective, there are over- or underincentives for vertical integration.