Distributive Justice in Supply Chains – Fair Distribution of Collectively Earned Profits in Supply Chains

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Abstract

The issue how to create profit in a network especially in supply chains is often discussed in scientific publications. But most of those scientific publications only analyze which structures, processes and actions can contribute to the creation of profit. How those collectively achieved profits can be distributed in a network of autonomous actors is often disregarded. Distributive justice, or fair distribution of collectively created profits, is one of the most important means of securing the stability of networks. This paper therefore presents a proposal for an operationalization of the fairness term from an economic perspective. This proposal is specific to the distribution of profits in networks of autonomously acting corporations and to especially supply chains. It is based on an innovative cooperative game theory approach, the χ-value. A simple and comprehensible example is used to illustrate the calculation of the χ-value.

1 Introduction

1.1 Research gap

Inter-organizational co-operation can generally be defined as *networks of autonomous actors*, in which every actor represents a legally autonomous corporation that hence is not subject to directions. In this paper it is also implied that co-operations are based on voluntary collaborations that are economically beneficial to each corporation involved. Such circumstances arise, for example, in supply chains that strictly speaking are supply webs, innovation and production networks, and virtual corporations. Supply chains as a special form of inter-organizational co-operations of legally autonomous corporations are in the focus of this paper.

The reason why corporations co-operate is to achieve special *profits* which cannot be realized without co-operating. The *creation of profits* in networks of autonomous actors, and especially supply chains, is often disputed. Basic theoretical considerations show that central coordination of collaboration based on the division of labor of several actors can never yield worse, and often yield better economic results than the aggregation of many partial plans that are locally "optimized" by each actor. However, total-planning models based on such a central coordination approach fail most of the time on account of unachievable assumptions relating to the availability of current and detailed information.

A large number of scientific publications and practical studies are devoted to the issue how to gain profits in supply chains or generally in co-operations. Those publications and studies show that the mutual adjustment of the actors with regard to their action plans as a central coordination approach normally yields higher economic values than if the actors optimize their action plans locally and without collaboration.[1] At the same time, the so-called bullwhip effect represents an important empirical indication for the possibility of collectively achieving profits in supply chains through co-operation.[2]

The bullwhip effect describes in particular how corporations build inventory buffers based on the demand of their customers: the further the corporation from the final customer, the greater the "safety stock" in times of rising demand. The cost of capital invested in oversized stock inventory buffers causes inefficiency, and thus co-operation profits can be realized by jointly avoiding or reducing the bullwhip effect. Evidence of the practical relevance of the bullwhip effect to supply chain management is provided by studies of its financial consequences.[3] Based on available estimates of the cost of the bullwhip effect, corporations should be able to increase their profits – depending on the source – by 8.4 to 20.1%[4] or by 10 to 30%[5] by avoiding it.

1 cf. Li et al. (2009), pp. 88-99; Mahdavi et al. (2008), pp. 1-20; Saharidis et al. (2009), pp. 117-126; Xiao et al. (2009), pp. 1-15; Zhang (2006), pp. 283-295.

2 cf. Lee et al. (1997), p. 78; see also Croson/Donohue (2006), pp. 323-336; Keller (2004), p. 11; Krol et al. (2005), pp. 281-289; McCullen/Towill (2002), p. 164; Metters (1997), S. 89-94.

3 cf. McCullen/Towill (2002), p. 164; Metters (1997), pp. 93-97.

4 cf. McCullen/Towill (2002), p. 170.

5 cf. Metters (1997), pp. 89.

Most scientific publications on the subject of supply chain management *only* analyze which structures, processes and actions can contribute to the co-operative *creation* of profits. But how the *distribution* of profits that were collectively achieved in an inter-organizational supply chain can influence the stability of such a supply chain is often *disregarded.* For example, Sarmah, Acharya and Goyal note after an extensive overview of the state of the art in achieving co-operation profits by supply chain management: "Most of these papers have ignored the mechanism to divide the surpluses generated due to coordination between the parties"[6]. In a similar way, Crook and Combs observe that: "Little attention has been paid to how the gains attributable to SCM are distributed"[7].

This neglect of those distribution aspects represents a significant *research gap*. The formation and the drifting apart of networks generally depend on the actors accepting the collectively gained profit as fair. If they regard the distribution of hoped for or already realized co-operation profits as fair they form a network or stay in it. If only one or more actors of a network perceive that the co-operation profit is not distributed in a fair way especially if his share of the profit seems to him to be too small, he would not continue to collaborate within the network. Consequently the network would fall apart.

Distributive justice, or fair distribution of collectively created profits, is accordingly one of the most important approaches to secure the stability of networks in political, socio-scientific and behavior-economic publications on the subject of network theory.

1.2 Scientific Problem

This paper examines the *scientific problem* of how the co-operation profits can be distributed to the actors as network partners in such a way that all actors regard the *distribution outcome* as *fair*. To solve this problem, *scientific methods* from the area of *game theory* will be applied. Aspects informing the choice of methods are that the networks or supply chains considered here consist of legally independent corporations (autonomous actors), who each pursue their own interests and do not have to comply with the instructions of their co-operation partners.

The *relevant literature* includes multiple contributions that draw on cooperative game theory to try and answer the problem of how profits that were collectively achieved in a network of autonomous actors can be distributed among the network partners in a fair way. Examples include the analysis of Cachon and Zipkin, Fromen, Gjerdrum et al., Inderfurth and Minner, Minner, Sucky, Thun as well as Voß and Schneidereit.[8] These contributions cannot be referenced in detail on account of the brevity of this article. However, they all share common ground in that they only cover the scientific and practical problem of *fairness* of co-operation profit distributions superficially.

6 cf. Sarmah et al. (2007), p. 1470.

7 cf. Crook/Combs (2007), p. 546.

8 cf. Cachon/Zipkin (1999); Fromen (2004); Gjerdrum et al. (2001); Inderfurth/Minner (2001); Minner (2007), pp. 579-582; Sucky (2004a), pp. 189-218; Sucky (2004b), pp. 493-513.; Sucky (2005), pp. 258-261; Thun (2005) and Voß/Schneidereit (2002).

Usually, a solution concept from cooperative game theory is used, whose fairness or acceptability is implied, but not closely reflected. This applies above all for the application of the Shapley value[9], the nucleolus[10] as well as the cooperative Nash solution.[11] Only Fromen discusses a wide selection of different solution concepts of cooperative game theory.[12] He examines them mostly from a mathematical and analytical perspective, but not from the pragmatic viewpoint of their acceptability as fair solution concepts.[13]

1.3 Solution approach

In this paper an *innovative approach* to fair distribution outcomes is presented. This approach rejects the idea of taking a solution concept from cooperative game theory as a "given" and applying it to a profit distribution problem on the naive assumption that the resulting distribution outcome will be accepted as fair. By making assumptions regarding the rationality of the actors it instead limits gradually the space of generally possible outcomes. If these assumptions are accepted as "reasonable", the result is a specific solution concept from cooperative game theory rarely found in the economic literature, the so-called χ-value. The *fairness* of the χ-value and the associated distribution outcomes is *justified* by the acceptability of the gradually established assumptions regarding the "reasonable" limitation of the valid solution space. It will be shown that these assumptions cannot be equated with the formalistic axioms of conventional game theory. It is not a matter of abstract, artificial mathematical characteristics, but of intuitively understandable and, from an economic perspective, strong assumptions to a game theory concept designed to solve the above mentioned scientific – but also practical – problem of fair distribution of co-operation profits in networks of autonomous actors.

2 Introduction to game theoretical solution concepts

The following four requirements are considered to be important for game theory modeling of the problem of determining fair distributions of profits:

1. It must be possible to explicate the different scopes for alternative distribution outcomes that emerge from different assumptions regarding the rationality of the actors.
2. Distribution outcomes determined by the solution concepts must be justifiable in order for the proposed solutions to be accepted as fair distribution outcomes.
3. The solution of the distribution problem must be communicated easily in the supply chain.
4. There must be only one unique solution to the distribution problem.

9 cf. Thun (2005); Voß/Schneidereit (2002); Shapley (1953).

10 e.g. Meertens/Potters (2006); Fromen 2004; Voß/Schneidereit (2002); Schmeidler (1969).

11 e.g. Sucky (2004a), pp. 201-205.

12 cf. Fromen (2004), pp- 95-142.

13 For a detailed discussion of the current situation outlined above, see Zelewski (2009), pp. 30–34.

The starting point for the cooperative distribution game is the *generic distribution problem* of distributing a profit or, synonymously, a co-operation profit G with $G \in \mathbb{R}_{>0}$ (where $\mathbb{R}_{>0}$ is the set of all positive real numbers) among the N autonomous actors A_n of a supply chain (with $n = 1,\dots,N$, $N \in \mathbb{N}$ and $N \geq 2$, where $\mathbb{N}$ is the set of all natural numbers). In cooperative game theory, a two-step standard approach to solving this generic distribution problem exists.

The first step is to develop a characteristic function c. This function refers to all possible coalitions which could be formed by the actors in the relevant supply chain. Moreover, "degenerate" coalitions formed by one actor are feasible. Therefore, a coalition C_m is a non-empty subset of the set A of all actors in the supply chain: $\varnothing \subset C_m \subseteq A$ with $A = \{A_1,\dots,A_N\}$. For each characteristic function c, it is assumed with $\wp$ as power set operator that: c: $\wp(A) \to \mathbb{R}_{\geq 0}$ with $C_m \to c(C_m)$ for each coalition C_m and $\varnothing \to c(\varnothing) = 0$. Such a characteristic function assigns the amount $c(C_m)$ the respective coalition C_m can claim with good reason. In the case of the grand coalition $C_0 = A$, this is the overall co-operation profit G: $c(C_0) = G$. For all other coalitions C_m with $\varnothing \subset C_m \subset A$, these are the amounts $c(C_m)$ these coalitions C_m could realize on their own outside the grand coalition C_0 and therefore in competition with the rest of the grand coalition, i.e. the residual coalition RC_m where $RC_m = C_0 \setminus C_m$.

In the second step, the shape of a distribution function v where v: $A \to \mathbb{R}_{\geq 0}$ and $A_n \to v(A_n) = v_n$ for each actor A_n is determined by calculating the distribution function values v_n. Only two information sources are considered to calculate these values. These are the amounts each feasible coalition C_m can claim due to the characteristic function c from the first step. At the same time the applied game theory solution concept specifies how the distribution function values v_n are calculated based on the values $c(C_m)$ of the characteristic function c for all feasible coalitions C_m where $m = 0,1,\dots,2^N$-2. When all distribution function values v_n are determined, the result is a N-tuple $v = (v_1,\dots,v_N)$ as a solution v for the respective regarded instance of the generic distribution problem. Every solution v assigns a share v_n of the co-operation profit G to each actor A_n of the supply chain. This N-tuple v is formally equivalent to a solution point L in the N-dimensional non-negative real number space $\mathbb{R}_{\geq 0}^N$. The solution point L is represented as a column vector $\vec{v}$, whose transposed representation denoted by a superscript letter (^{T}) is: $\vec{v} = (v_1,\dots,v_N)^T$.

From a management point of view, this standard approach of cooperative game theory is *unsatisfactory*. Its main weakness lies in the characteristic function c, which is assumed to be known in conventional game theory analyses. This information premise is rather unrealistic since in actual practice it is often not known for each feasible coalition C_m which value $c(C_m)$ is reasonably appropriate for the respective coalition. A practicable game theory solution concept should therefore make it possible to calculate the values v_n without full knowledge of the characteristic function c. Such a solution concept should refer to as few coalitions as possible to calculate the values v_n for all actors A_n. Minimal knowledge is thus added as a fifth requirement to be satisfied by any solution concept for the fair distribution of profits achieved in a supply chain.

3 Introducing the χ-value

3.1 Formulation of basic assumptions

The χ-value hearkens back to contributions by Bergantiños and Massó from 1994.[14] Up to now, it has only been picked up on rarely[15] and, in the area of economic research at least, is still widely unknown. The χ-value is a remarkable game theory solution concept for the generic distribution problem, as the following paragraphs will show.

The basic idea of the χ-value solution concept is to restrict the solution space $\mathbb{R}_{\geq 0}{}^{N}$ for the generic distribution problem by successively adding five assumptions which stem from the real problem of distributing profits achieved co-operatively in a supply chain among the co-operating actors. The following arguments yield to the χ-value as a "reasonable" solution to the generic distribution problem that is in principle acceptable as a fair distribution outcome.

The first assumption is the *condition of individual rationality*. This condition assumes that every actor in a supply chain acts rationally in the conventional sense of perfect rationality. This means that each actor maximizes his or her individual utility. The condition of individual rationality places a restriction on the solution space $\mathbb{R}_{\geq 0}{}^{N}$, since it would not be rational for an actor A_n to participate in the supply chain within the grand coalition C_0 if this coalition yields a smaller utility for this actor compared to if he or she left the coalition and realized the amount $c(\{A_n\})$ outside the supply chain. Thus the condition of individual rationality can be formulated with the characteristic function c and the feasible solution point L within the solution space as follows:

$$\forall L \in \mathbb{R}^{N}_{\geq 0}: \quad L = (v_1,\ldots v_N)^T \geq \left(c(\{A_1\}),\ldots,c(\{A_N\})\right)^T \tag{1}$$

The second assumption is the *efficiency condition*. This condition requires the profit or co-operation profit G to be distributed exactly ("efficiently") among all actors A_n of the grand coalition $C_0 = \{A_1,\ldots,A_N\}$. While it would be irrational to distribute less than the profit G, because this would necessarily entail a loss of Pareto optimality, it is also impossible to distribute more than the profit G. Thus the following equation will hold true for every feasible solution L and the value $c(C_0)$ of the characteristic function c:

$$\forall L \in \mathbb{R}^{N}_{\geq 0}: \quad L = (v_1,\ldots v_N)^T \rightarrow \sum\nolimits_{n=1}^{N} v_n = c(C_0) = G \tag{2}$$

A further restriction of the solution space $\mathbb{R}_{\geq 0}{}^{N}$ is implied by the efficiency condition. Hence all the solutions of the distribution problem that fulfill the assumption of efficiency are solution points L on a hyper plane H in the N-dimensional solution space $\mathbb{R}_{\geq 0}{}^{N}$. This hyper plane H is defined as the set of all solutions $v = (v_1,\ldots,v_N)$ of the distribution problem that fulfill the equation on the right hand side of the sub-junction of formula (2).

14 cf. Bergantiños/Massó (1994); Bergantiños/Massó (1996); Bergantiños et al. (2000); Bergantiños/Massó (2002).

15 e.g. Sánchez-Soriano (2000).

The third assumption is the rationality *condition for maximum allocable shares of the profit*. This condition has the character of a condition of collective rationality, since it mirrors the rational consideration of all N-1 actors of the so-called marginal coalition MC_n where $MC_n = C_0 \backslash \{A_n\} = \{A_1,\ldots,A_{n-1},A_{n+1},\ldots,A_N\}$ to grant actor A_n at most the share $v_{n.max}$ of the profit G, so that the profit G would decrease if actor A_n left the grand coalition $C_0 = \{A_1,\ldots,A_N\}$. This rationality condition requires the following where $c(C_0) = G$ from formula (2):

$$\forall n = 1,\ldots,N \ \forall v_n \in \mathbb{R}_{\geq 0}: \\ v_n \leq v_{n.max} \wedge v_{n.max} = c(C_0) - c(MC_n) = G - c(MC_n) \tag{3}$$

This assumption can be generalized in such a way that the profit $c(C_m)$ of *each* coalition C_m *including* actor A_n would decrease if actor A_n left this coalition C_m. It follows that the maximum allocable share $v_{n.max}$ of the profit G for one actor A_n is measured by the maximum amount $c(C_m)$ - $c(C_m \backslash \{A_n\})$ that the profit $c(C_m)$ of *each* coalition C_m *including* actor A_n would decrease if actor A_n left this coalition C_m. For the reasons mentioned above, the third assumption will be replaced for the χ-value by the following generalized rationality condition for maximum allocable shares $v^{\chi}_{n.max}$:

$$\forall n = 1,\ldots,N \ \forall v_n \in \mathbb{R}_{\geq 0}: \quad v_n \leq v^{\chi}_{n.max} \wedge \ldots \\ v^{\chi}_{n.max} = max\left\{ c(C_m) - c(C_m \backslash \{A_n\}) \,\middle|\, \varnothing \subset C_m \subseteq A \wedge \{A_n\} \subset C_m \right\} \tag{4}$$

In the solution space, the point at which the maximum allocable share $v^{\chi}_{n.max}$ of the profit G is assigned to each actor A_n is called the upper bound *UB* or *ideal point* for the distribution of the profit G.

The fourth assumption is a *rationality condition for minimum allocable shares of the profit*. This condition also has the character of a collective rationality condition, since it reflects the rational consideration of all N-1 actors of the marginal coalition MC_n where $MC_n = C_0 \backslash \{A_n\}$ to grant actor A_n at least the share $v_{n.min}$ of the profit G with which he or she could credibly threaten to found at least one so-called outsider coalition $AC_{n.q}$. An outsider coalition is a coalition $AC_{n.q}$ of former actors of the grand coalition, which leaves the grand coalition C_0 at least hypothetically and has the actor A_n as "leader". Since the same actor A_n can lead several outsider coalitions, the second index q is used to differentiate all outsider coalitions led by the same actor A_n.

For the χ-value, it is important which outsider coalitions $AC_{n.q}$ enable an actor A_n to threaten in a believable manner. In this paper, it is assumed that the characteristic function is partially known due to the amounts $c(AC_{n.q})$ for each outsider coalition led by an actor A_n. The actor A_n offers all other actors of the outsider coalition $AC_{n.q}$ an optimal incentive to defect. This incentive consists of so-called side payments and ensures that the utility of each other actor from the outsider coalition $AC_{n.q}$ is the same as his or her maximum utility as part of the grand coalition C_0. In this case, the actors in an outsider coalition have no incentive to remain in the grand coalition C_0. The operationalization of the side payments takes place in the following way, with the amount $c(\{A_n\}|AC_{n.q})$ realizable by actor A_n in the outsider coalition $AC_{n.q}$ and with the index set $IN_{n.q}$ of indices of all actors belonging to this outsider coalition:

$$\forall \varnothing \subset AC_{n.q} \subset A: \{A_n\} \subset AC_{n.q} \rightarrow \ldots$$
$$c(\{A_n\}|AC_{n.q}) = c(AC_{n.q}) - \sum_{m \in (IN_{n.q} \setminus \{n\})} v^{\chi}_{n.max} \qquad (5)$$

The amounts $c(\{A_n\}|AC_{n.q})$ utilized by actor A_n in threatening to found an outsider coalition may be negative. There are two reasons for this. Firstly, the sum $\sum_{m \in (IN_{n.q} \setminus \{n\})} v^{\chi}_{n.max}$ of the side payments can be greater than the amount $c(AC_{n.q})$ realized by the outsider coalition $AC_{n.q}$. In this case, the leading actor A_n must withdraw the partial amount $\sum_{m \in (IN_{n.q} \setminus \{n\})} v^{\chi}_{n.max} - c(AC_{n.q})$ from savings or even incur debt. Secondly, if actor A_n is the sole actor in the outsider coalition $AC_{n.q}$ and thus the above mentioned side payments are not required, the amount $c(\{A_n\})$ may be negative as well. Actor A_n, for example, may not be competitive in the market without collaborating in the co-operation, for example, in a supply chain. In both cases, where $c(\{A_n\}|AC_{n.q}) < 0$, a threat would not be believable. Thus both cases are excluded from the rationality condition for minimum allocable shares of the profit. The complete rationality condition for minimum shares $v^{\chi}_{n.min}$ of the profit G to be allocated is as follows:

$$\forall n = 1,\ldots,N \; \forall v_n \in \mathbb{R}_{\geq 0}: v_n \geq v^{\chi}_{n.min} \;\wedge\; v^{\chi}_{n.min} = max\{c_{n.1}; c_{n.2}; 0\}$$

where:

$$c_{n.1} = c(\{A_n\} \mid AC_{n.q}) = c(\{A_n\}) \;\; for \;\; AC_{n.q} = \{A_n\}$$

$$c_{n.2} = max\left\{ c(\{A_n\} \mid AC_{n.q}) = c(AC_{n.q}) - \sum_{m \in (IN_{n.q} \setminus \{n\})} v^{\chi}_{m.max} \;\middle|\; \ldots \;\; \varnothing \subset AC_{n.q} \subseteq A \;\wedge\; \{A_n\} \subset AC_{n.q} \right\} \qquad (6)$$

As a side effect of this formulation of the rationality condition for minimum allocable shares of the profit, the condition of individual rationality according to formula (1) is implicitly covered as a borderline case of outsider coalitions $AC_{n.q}$ only including one actor A_n because of term $c_{n.1}$ in formula (6). Hence the condition of individual rationality does not in principle need to be listed explicitly as an assumption according to formula (1). In this article, however, it will be used to show that the condition of individual rationality is always respected.

The lower bound LB for the distribution of the profit G is that point in the solution space $\mathbb{R}_{\geq 0}^{N}$ at which the minimum allocable share $v_{n.min}$ of the profit G is assigned to each actor A_n. The lower bound $v^{\chi}_{n.max}$ is often called the *threat point*.

The fifth and last assumption is introduced as an *integrity condition* for the relation of the lower bound LB to the upper bound UB for the shares of the profit G to be distrib-

uted, as well as for the hyper plane H for compliance with the efficiency condition, in order to avoid certain complications outside the scope of this paper (for details of these complications due to the closely related τ-value see Zelewski, 2009, pp. 137-141 and 156-167):

$$\forall LB, UB \in \mathbb{R}^N_{\geq 0} \; \forall G \in \mathbb{R}_{>0}:$$
$$\left(LB = \begin{pmatrix} v^{\chi}_{1.min} \\ \ldots \\ v^{\chi}_{N.min} \end{pmatrix} \wedge UB = \begin{pmatrix} v^{\chi}_{1.max} \\ \ldots \\ v^{\chi}_{N.max} \end{pmatrix} \wedge c(C_0) = G \right) \qquad (7)$$
$$\rightarrow \left(\sum_{n=1}^{N} v^{\chi}_{n.min} \leq G \leq \sum_{n=1}^{N} v^{\chi}_{n.max} \;\wedge\; LB \leq UB \right)$$

3.2 *The solution point of the χ-value*

It can be shown that exactly one solution point L in the N-dimensional non-negative real number space $\mathbb{R}_{\geq 0}^{N}$ fulfills all five aforementioned assumptions for the generic distribution problem concerning individual and collective rationality, as well as efficiency and integrity, i.e. the formulas (1), (2), (4), (5), and (7). This unique solution point is the χ-value. The χ-value is a special solution point L_χ, which is determined by a convex or, in less precise but more intuitive terms, linear combination of the upper bound (ideal point) UB and the lower bound (threat point) LB with the weighting factor γ and $0 \leq \gamma \leq 1$. Therefore it must hold true that:

$$\forall L, LB, UB \in \mathbb{R}^N_{\geq 0} \; \forall G \in \mathbb{R}_{>0}:$$
$$\left(L = \begin{pmatrix} v_1 \\ \ldots \\ v_N \end{pmatrix} \wedge \sum_{n=1}^{N} v_n = G \wedge LB = \begin{pmatrix} v^{\chi}_{1.min} \\ \ldots \\ v^{\chi}_{N.min} \end{pmatrix} \wedge UB = \begin{pmatrix} v^{\chi}_{1.max} \\ \ldots \\ v^{\chi}_{N.max} \end{pmatrix} \wedge G \geq \sum_{n=1}^{N} c(\{A_n\}) \right) \qquad (8)$$
$$\rightarrow \left(\dot{\exists} L_\chi \in \mathbb{R}^N_{\geq 0} \; \dot{\exists} \gamma \in \mathbb{R}_{\geq 0}: \; L_\chi = \gamma \bullet LB + (1-\gamma) \bullet UB \;\wedge\; 0 \leq \gamma \leq 1 \right)$$

After some simple transformations using the efficiency condition and with special regard to the frequently neglected degenerated case $\sum_{n=1}^{N} v^{\chi}_{n.max} = \sum_{n=1}^{N} v^{\chi}_{n.min}$, the common formula for calculating the χ-value produces:

$$\forall n = 1,\ldots,N: \;\; v^{\chi}_{n} = \gamma \bullet v^{\chi}_{n.min} + (1-\gamma) \bullet v^{\chi}_{n.max} \qquad (9)$$

where:

$$\gamma = \frac{G - \sum_{n=1}^{N} v^{\chi}_{n.min}}{\sum_{n=1}^{N} v^{\chi}_{n.max} - \sum_{n=1}^{N} v^{\chi}_{n.min}}; \quad \text{if } \sum_{n=1}^{N} v^{\chi}_{n.max} \neq \sum_{n=1}^{N} v^{\chi}_{n.min}$$
$$\gamma \in [0;1]; \quad \text{if } \sum_{n=1}^{N} v^{\chi}_{n.max} = \sum_{n=1}^{N} v^{\chi}_{n.min} \qquad (10)$$

3.3 The χ-value in comparison to the τ-value

As before mentioned the in this paper introduced χ-value is closely related to the slightly more known τ-value. The τ-value was proposed for the first time by Tijs in 1980 as part of the "Seminar on game theory and mathematical economics"[16]. It was further developed by Tijs and Driessen.[17]

The χ-value can be seen as a generalization of the τ-value, because the χ-value has the same structure as the τ-value, and only one central assumption of the τ-value is replaced by a generalized assumption. In this context, the same structure means that the χ-value and the τ-value are so-called compromise solution concepts. They can be characterized by the solution for an instance of the generic distribution problem that is determined as a compromise value that mediates between an upper bound for maximum allocable shares of the profit and a lower bound for minimum allocable shares of the profit. The mediation between upper and lower bound is operationalized by the calculation of a convex combination of both bounds.

The difference between the χ-value and the τ-value is the limitation of the τ-value to quasi-balanced games. This limitation to quasi-balanced games can also be seen as a substantial weakness of the τ-value. The χ-value picks up on this weakness of the τ-value. It can be shown that the χ-value works without the integrity condition of quasi-balanced games.[18]

The central modification of the χ-value compared to the τ-value is made in the assumption concerning the *maximum* allocable shares of the co-operation profit. With the τ-value, the maximum allocable share $v_{n.max}$ of the profit G for an actor A_n is *only* measured by the amount $c(C_0)$ - $c(C_0 \setminus \{A_n\})$ by which the profit G of the *grand* coalition $C_0 = \{A_1,...,A_N\}$ would decrease if actor A_n left this grand coalition C_0. By contrast with the χ-value, the maximum allocable share $v_{n.max}$ of the profit G for one actor A_n is measured by the amount $c(C_m)$ - $c(C_m \setminus \{A_n\})$ the profit G of *each* coalition C_m *including* actor A_n would decrease if actor A_n left this coalition C_m. Given that actor A_n always belongs to grand coalition C_0, the limitation of the calculation of $v_{n.max}$ at the τ-value to the grand coalition C_0 represents a special case of the calculation of $v_{n.max}$ at the χ-value with $C_m = C_0$. Given that the χ-value in addition to the grand coalition C_0 also includes more coalitions C_m with $C_m \subset C_0$ in the calculation of $v_{n.max}$, according to this additional coalitions C_m the χ-value represents a *generalization* G of the τ-value.

16 cf. Tijs (1981).

17 cf. Driessen (1985); Driessen/Tijs (1982); Driessen/Tijs (1983); Driessen/Tijs (1985); Tijs (1987); Tijs/Driessen (1983); Tijs/Driessen (1986); see also Curiel (1997) and Zelewski (2009).

18 Bergantiños/Massó (1996), pp. 280-281.

4 A simple example for calculating the χ-value

4.1 Purpose of the example

The following example is artificially generated to keep it simple and comprehensible. The purpose of this example is to show how the χ-value can be applied in management practice to solve the problem of fair distribution of profits in supply chains.

This example should also illustrate what information is required in management practice in order to apply the χ-value in calculating profit distributions. In this example the necessary information is given. The gathering of the necessary information is neglected. In management practice, obtaining all values of the characteristic function c for all possible coalitions could prove particularly difficult. The problem of information gathering in practice will be addressed later on in chapter 5.

4.2 Calculation

For illustrative purposes, a simply structured fictitious example is considered. It is restricted to the number of $N = 5$ actors. The numerical values are chosen so that the necessary calculations remain relatively easy.

The numerical example considers a supply chain with 5 actors: $A_1,...,A_5$. In the last corporation year, the actors jointly realized a profit G of \$ 100,000. This profit is to be distributed among the actors in a manner that these actors accept as fair. Firstly, to ensure the comparability with other game theory solution concepts, it is assumed that the values of the characteristic function c for the generic distribution game are known. Thus the values $c(C_m)$ are known for every possible coalition C_m which can be formed from the set of actors $A = \{A_1,...,A_5\}$. The values $c(C_m)$ are given in table 1 for all 2^5-1 = 31 coalitions C_m where $m = 0,1,2,...,30$.

C_m	$c(C_m)$	C_m	$c(C_m)$	C_m	$c(C_m)$
$C_0=\{A_1,A_2,A_3,A_4,A_5\}$	100,000				
$C_1=\{A_1\}$	0	$C_{11}=\{A_2,A_4\}$	25,000	$C_{21}=\{A_1,A_4,A_5\}$	55,000
$C_2=\{A_2\}$	0	$C_{12}=\{A_2,A_5\}$	30,000	$C_{22}=\{A_2,A_3,A_4\}$	50,000
$C_3=\{A_3\}$	0	$C_{13}=\{A_3,A_4\}$	30,000	$C_{23}=\{A_2,A_3,A_5\}$	55,000
$C_4=\{A_4\}$	5,000	$C_{14}=\{A_3,A_5\}$	35,000	$C_{24}=\{A_2,A_4,A_5\}$	65,000
$C_5=\{A_5\}$	10,000	$C_{15}=\{A_4,A_5\}$	45,000	$C_{25}=\{A_3,A_4,A_5\}$	70,000
$C_6=\{A_1,A_2\}$	0	$C_{16}=\{A_1,A_2,A_3\}$	25,000	$C_{26}=\{A_1,A_2,A_3,A_4\}$	60,000
$C_7=\{A_1,A_3\}$	5,000	$C_{17}=\{A_1,A_2,A_4\}$	35,000	$C_{27}=\{A_1,A_2,A_3,A_5\}$	65,000
$C_8=\{A_1,A_4\}$	15,000	$C_{18}=\{A_1,A_2,A_5\}$	40,000	$C_{28}=\{A_1,A_2,A_4,A_5\}$	75,000
$C_9=\{A_1,A_5\}$	20,000	$C_{19}=\{A_1,A_3,A_4\}$	40,000	$C_{29}=\{A_1,A_3,A_4,A_5\}$	80,000
$C_{10}=\{A_2,A_3\}$	5,000	$C_{20}=\{A_1,A_3,A_5\}$	45,000	$C_{30}=\{A_2,A_3,A_4,A_5\}$	90,000

Tab. 1: Values of the characteristic function c for all coalitions C_m

A prerequisite for calculation of the χ-value as a solution $\underline{v}_\chi$ where $\underline{v}_\chi = (v_{1.\chi}, \ldots, v_{N.\chi})$ for the generic distribution game is that the values of the characteristic function c for all three types of coalition are available. That is, $c(C_0)$ must be available for the grand coalition $C_0 = \{A_1,\ldots,A_5\}$, while $c(MC_n)$ is required for each marginal coalition MC_n where $n = 1,\ldots,5$ and $c(AC_{n.q})$ must be known for each outsider coalition $AC_{n.q}$. The value $c(C_0) = 100{,}000$ for the grand coalition C_0 is immediately available from table 1, since, according to the efficiency condition, the entire profit $G = 100{,}000$ must be distributed exactly among all 5 actors $A_1,\ldots,A_5$ in the supply chain. The values $c(MC_n)$ for the marginal coalitions MC_n where $n = 1,\ldots,5$ can be determined with the aid of the definition $MC_n = C_0 \backslash \{A_n\}$ (results in table 2).

MC_n	$c(MC_n)$
MC_1	$c(\{A_1,\ldots,A_5\} \setminus \{A_1\}) = c(\{A_2,A_3,A_4,A_5\}) = 90{,}000$
MC_2	$c(\{A_1,\ldots,A_5\} \setminus \{A_2\}) = c(\{A_1,A_3,A_4,A_5\}) = 80{,}000$
MC_3	$c(\{A_1,\ldots,A_5\} \setminus \{A_3\}) = c(\{A_1,A_2,A_4,A_5\}) = 75{,}000$
MC_4	$c(\{A_1,\ldots,A_5\} \setminus \{A_4\}) = c(\{A_1,A_2,A_3,A_5\}) = 65{,}000$
MC_5	$c(\{A_1,\ldots,A_5\} \setminus \{A_5\}) = c(\{A_1,A_2,A_3,A_4\}) = 60{,}000$

Tab. 2: Values of the characteristic function c for all marginal coalitions MC_n

The values $c(AC_{n.q})$ for the outsider coalitions $AC_{n.q}$, where $n = 1,\ldots,5$, can be obtained immediately from table 1. However, calculation of these values $c(AC_{n.q})$ requires a tremendous amount of work, since 75 (5•15 = n•q) feasible outsider coalitions must be considered. This calculation is therefore omitted for space reasons. It is significant that for the calculation of the values $c(AC_{n.q})$ for all possible combinations of outsider coalitions $AC_{n.q}$, the values of the characteristic function c for all possible coalitions C_m with $\varnothing \subset C_m \subset C_0$ need to be determined. Hence the above mentioned fifth requirement of minimal knowledge is not fulfilled by the χ-value. This is surprising, since it appears from the formulas (1) to (6) that, to determine the χ-value, only those values of the characteristic function c must be known that refer to the grand coalition C_0, the marginal coalitions MC_n and the outsider coalitions $AC_{n.q}$. Only the concrete numeric calculation of the χ-value for the example considered here shows that calculation of the values $c(AC_{n.q})$ for the outsider coalitions $AC_{n.q}$ indirectly leads to the fact that the values $c(C_m)$ of the characteristic function c for *all* possible coalitions C_m with $\varnothing \subset C_m \subset C_0$ must be known.

The components $v_{n.max}$ of the upper bound *UB* (ideal point) are calculated with formula (3) on the basis of the values $c(C_0)$ and $c(MC_n)$ instead of the more complicated formula (4). This possibility of simplification relies on the fact that the example used here is a *convex game* (Curiel 1997, p. 3; Fromen 2004, p. 87; Zelewski 2009, p. 216). It was proven for the class of *convex games* that the χ-value coincides with the τ-value. Because the τ-value is calculated with the aid of formula (3), it is sufficient to use this formula here.

The value $c(C_0)$ is immediately given by the profit G to be distributed: $c(C_0) = G = 100{,}000$. Thus the components $v^\chi_{n.max}$ of the upper bound *UB* of the χ-value are those shown in table 3.

A_n	$v^\chi_{n.max}$
A_1	$c(C_0)$-$c(MC_1) = 100{,}000 - 90{,}000 = 10{,}000$
A_2	$c(C_0)$-$c(MC_2) = 100{,}000 - 80{,}000 = 20{,}000$
A_3	$c(C_0)$-$c(MC_3) = 100{,}000 - 75{,}000 = 25{,}000$
A_4	$c(C_0)$-$c(MC_4) = 100{,}000 - 65{,}000 = 35{,}000$
A_5	$c(C_0)$-$c(MC_5) = 100{,}000 - 60{,}000 = 40{,}000$

Table 3: Components $v^\chi_{n.max}$ of the upper bound *UB* of the χ-value

The components $v^\chi_{n.min}$ of the lower bound *LB* (threat point) of the χ-value are calculated with formula (6) for each of the 5 actors A_1 to A_5. This calculation is shown as an example for actor A_4:

$$v^\chi_{4.min} = max\{c_{4.1}; c_{4.2}; 0\} = max\{5{,}000; 5{,}000; 0\} = 5{,}000$$

Because:

$$c_{4.1} = c(\{A_4\} \mid AC_{4.1}) = c(\{A_4\}) = 5{,}000$$

$$c_{4.2} = max\left\{c(\{A_4\} \mid AC_{4.q}) = c(AC_{4.q}) - \sum\nolimits_{m \in (IN_{4.q} \setminus \{4\})} v^\chi_{m.max} \,\middle|\, q = 2,\ldots,15\right\} = 5{,}000$$

From the components $v^\chi_{n.max}$ of the upper bound *UB* and the components $v^\chi_{n.min}$ of the lower bound *LB* calculated above, it follows that the standard case for calculation of the χ-value with $\sum\nolimits_{n=1}^{N} v^\chi_{n.max} \neq \sum\nolimits_{n=1}^{N} v^\chi_{n.min}$ applies. According to formula (10), the weighting factor γ is as follows:

$$\gamma = \frac{G - \sum\nolimits_{n=1}^{N} v^\chi_{n.min}}{\sum\nolimits_{n=1}^{N} v^\chi_{n.max} - \sum\nolimits_{n=1}^{N} v^\chi_{n.min}}$$

$$= \frac{100{,}000 - (0+0+0+5{,}000+10{,}000)}{(10{,}000+20{,}000+25{,}000+35{,}000+40{,}000) - (0+0+0+5{,}000+10{,}000)}$$

$$= \frac{17}{23} \approx 0{,}74$$

4.3 *Result of the calculation*

The components $v_{n.\chi}$ of the χ-value $\underline{v}_\chi$ are then calculated in table 4 for each actor A_n using formula (10) and the weighting factor $\gamma = {}^{17}/_{23}$ as the convex combination of the components $v^\chi_{n.max}$ of the upper bound *UB* (threat point) and the components $v^\chi_{n.min}$ of the lower bound *LB* (threat point) for the χ-value.

A_n	$v_{n.\chi}$
A_1	$^{17}/_{23}\cdot 10{,}000 + {}^{6}/_{23}\cdot 0 = {}^{1}/_{23}\cdot 170{,}000$
A_2	$^{17}/_{23}\cdot 20{,}000 + {}^{6}/_{23}\cdot 0 = {}^{1}/_{23}\cdot 340{,}000$
A_3	$^{17}/_{23}\cdot 25{,}000 + {}^{6}/_{23}\cdot 0 = {}^{1}/_{23}\cdot 425{,}000$
A_4	$^{17}/_{23}\cdot 35{,}000 + {}^{6}/_{23}\cdot 5{,}000 = {}^{1}/_{23}\cdot 625{,}000$
A_5	$^{17}/_{23}\cdot 40{,}000 + {}^{6}/_{23}\cdot 10{,}000 = {}^{1}/_{23}\cdot 740{,}000$

Table 4: Components $v_{n.\chi}$ of the χ-value v_χ

In the end, exactly one χ-value $\underline{v}_\chi$ exists as a unique solution with $\underline{v}_\chi = {}^{1}/_{23}\cdot(170{,}000;$ $340{,}000; 425{,}000; 625{,}000; 740{,}000)$. This means that the \$ 100,000 profit that was collectively earned by all five actors will be distributed as follows:

A_n	*share of collectively earned profit*
A_1	\$ 7,391.31
A_2	\$ 14,782.61
A_3	\$ 18,478.26
A_4	\$ 27,173.91
A_5	\$ 32,173.91

Table 5: shares per actor

5 Conclusion

This article has shown how the vague understanding of fairness that dominates in practice can be defined with the aid of game theory by applying the game theory solution concepts to the generic distribution problem. The solution concept the χ-value was introduced and explained. Special attention was paid to the fact that the χ-value inevitably results if a small number of assumptions with respect to individual and collective rationality, efficiency and integrity are accepted. This matches the justification program introduced at the beginning and presents a game theory solution concept in which good reasons are cited in order for the resulting solutions to be accepted as fair distribution.

In the authors' view, the assumptions that the χ-value is based on are so straightforward that the solution concept has *great potential* for *general acceptance.* Other game theory solution concepts, for example the Shapley value and the nucleolus, demand the acceptance of far more abstract, often only formally precisely definable assumptions. Hence they have considerably lower general acceptance potential. Additionally, other game theory solution concepts, for example the core of a game, can be traced back to a few plausible assumptions. However, they have the disadvantage that they do not exist

for many instances of the generic distribution problem or have multiple, often even infinite, solutions.

For the aforementioned reasons, the χ-value offers to unite the advantage of *good reasonability* of the *acceptability* of distribution outcomes as *fair* with the pragmatic assumptions of the *existence* and *clearness* for a – in relation to other game theory solution concepts – broad range of instances of the generic distribution problem. The χ-value proves superior to the already mentioned closely related τ-value regarding its implementation range. Due to its wider implementation range it must therefore be accepted that the χ-value induces a higher calculation effort as at the τ-value.

As *managerial insights* three aspects can be gained from above explanations. Firstly, game theory solution concepts such as the χ-value offer a "reasonable", that is, provable with *good reason*, and justifiable *basis* for the *distribution of profits* in supply chains. Thanks to the explicability of the good reasons, there is a high chance that the corporations will accept the distribution as *fair*. However, distribution of profits calculated using the χ-value can always only represent the basis of a discussion about the fair distribution of a collectively realized profit, not the final outcome of the distribution. Like any other concept for distributing profits, the χ-value is based on specific assumptions, which can, but need not, be accepted as „reasonable". Propositions for the distribution of co-operation profits on the basis of the χ-value thus indeed form a promising basis for discussion, because such a distribution proposition can be justified with good reasons. However, good reasons never offer an assurance that – especially on the basis of other assumptions – even more convincing reasons for an alternative distribution proposition can be found.

Secondly, it was implied in this contribution that the *profit G can be defined precisely* and quantified monetarily, but that this assumption will only rarely be fulfilled in practice. This can lead to two basic practical problems. On the one hand, agreement needs to be reached as to the concrete economic scale on which the profit to be distributed is to be determined and from which sources the information required to determine it can be drawn. This is not a trivial task and cannot be analysed in detail in this article. On the other hand, how the management of a supply chain is defined needs to be clarified, because a value chain according to the agreements made at the beginning is characterized by the co-operation of legally autonomous corporations (autonomous actors). If a supply chain is dominated by one focal corporation, it is relatively simple to equate the management of a supply chain with the management of the focal corporation. However, as a side condition it must be considered that the management of the focal corporation can only make decisions that do not jeopardize the stability of the supply chain – and from a game theory perspective the stability of the grand coalition. There is also the question of how the management of a supply chain is defined, if the special case of a focal corporation does not apply. In this non-focal case, one option is to revert to the game theory concept of coalition formation games. With the aid of this concept, it is possible to examine how coalitions of legally autonomous corporations in (the form of) a supply chain come about. However, even such coalition formation games so far offer no starting points at which to determine how, in supply chains without a focal corporation, the profit to be distributed should be determined in concrete terms. Extensive academic research is still required on this point.

Thirdly, the management of corporations co-operating in a supply chain must always be aware of the fact that game theory solution concepts assume the rationality of all involved actors (corporations). Negotiations in real existing supply chains about the "fair" distribution of profits are by no means always guided by the rationality of the negotiating partners. Rather, management must be aware that the process of negotiation on the fair distribution of profits also influences the fact that conceptions of rationality do not correspond to classic game theory. Influences "beyond" the conceptions of rationality of classic game theory are not covered by the game theory solution concept introduced here.

The χ-value thus represents an interesting approach and allows the aspect of bargaining power to be included in determining distribution outcomes which can be accepted as fair.

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Prävention von Transportschäden durch den Einsatz von Sensor-Telematik-Systemen aus der Versicherungsperspektive

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Zusammenfassung

Die steigende Komplexität der Transport- und Logistikprozesse führt zu einer Vielzahl von Risiken und Gefahren bei den Transportakteuren und Versicherungen. Die global verteilten Produktions- und Absatzmärkte sind eine Ursache, dass immer mehr und höherwertigere Güter in weltumspannenden Logistiknetzwerken transportiert werden. Aufgrund des steigenden Wettbewerbsdrucks unter den Logistikdienstleistern bündeln diese vermehrt Transporte zu größeren Transporteinheiten und lagern zeitunkritische Sendungen teilweise zwischen. Dies erhöht für die Versicherungen das Risiko von Kumulschäden und kann bei größeren Schäden beim Warenempfänger für Lieferengpässe bzw. zu Betriebsunterbrüchen führen. Gleichzeitig sind detaillierte Informationen über den Zustand von Waren und ihrer Integrität innerhalb der Lieferkette nicht durchgehend vorhanden und die genauen Bedingungen während des Transports bleiben intransparent. Sensor-Telematik-Systeme werden heute bereits von führenden Logistikdienstleistern und Frachtführern z.B. auf ausgesuchten Routen oder für hochwertige Waren eingesetzt. Durch diese Entwicklungen werden ebenso Risiken sowohl für den Transportversicherer als auch für die Transportakteure identifizier- und messbar, was die Grundlage von effektiven präventiven, schadensmindernden Maßnahmen bildet. Der Technologieeinsatz mündet in ein situativ an die jeweiligen Transportcharakteristika angepasstes Risikomanagement. Welche Einflüsse, Potentiale sowie Risiken aus dem Technologieeinsatz im Transportbereich erwachsen, soll im Rahmen des vorliegenden Beitrags diskutiert werden. Vor diesem Hintergrund analysiert dieser Beitrag das Schadenreduktionspotential eines Einsatzes von Sensor-Telematik-Systemen im Transportbereich in drei Schritten: (1) Zur Identifikation der aktuellen Problemstellungen und Transportrisiken im globalen Warenverkehr werden die Kernergebnisse einer Schadendatenanalyse bei einer der führenden europäischen Transportversicherung vorgestellt. (2) Im Anschluss werden die Ergebnisse der quantitativen Schadendatenanalyse anhand von 25 Experteninterviews weiter verdichtet und verallgemeinert. (3) Den Abschluss der Untersuchung bildet die Zusammenstellung der quantitativ-qualitativ erhobenen Ergebnisse und Ableitung der Wirkungspotentiale von Sensor-Telematik-Systemen zur Prävention von Transportschäden.

5 | Logistik und Supply Chain Management

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Das erfolgreiche Management sowohl unternehmensinterner als auch unternehmensübergreifender Wertschöpfungsprozesse, Wertschöpfungsketten und ganzer Wertschöpfungsnetzwerke basiert im Besonderen auf dem zielgerichteten Einsatz von bestehenden und weiterentwickelten Methoden und Konzepten des Produktions- und Logistikmanagements sowie des Operations Research, dem Einsatz von innovativen Informations- und Kommunikationstechnologien sowie theoretischen und praktischen Erkenntnissen des Kooperationsmanagements. Die Schriftenreihe dient der Veröffentlichung neuer Forschungsergebnisse auf den Gebieten Logistik und Supply Chain Management. Aufgenommen werden Publikationen, die einen Beitrag zum wissenschaftlichen Fortschritt in Logistik und Supply Chain Management liefern.