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Original Article

Data envelopment analysis for investigating the relative efficiency of supply chain management

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ABSTRACT

Despite the growing popularity of supply chain management (SCM) both among managers and scholars, the efficiency of implementation of SCM has been barely assessed in an analytic way. The purpose of this study is to shift the attention of SCM scholars towards an in-depth investigation of SCM efficiency by reporting procedure and outcomes of one possible methodological approach. The current study investigates the relative efficiency of SCM implementation (in terms of ratio of various outputs to inputs) and subsequently identifies influencing factors. This procedure is illustrated by an empirical application based on a European sample of manufacturing plants as Decision Making Units (DMUs), following a two-step approach. (1) Data envelopment analysis (DEA) assesses the relative efficiencies of SCM implementation of DMUs. (2) Subsequently, factors fostering or impeding SCM efficiency are explored through a bootstrapped truncated regression model. Our analysis finds that factors influencing relative SCM efficiency refer to country affiliation, characteristics of manufacturing plants, characteristics of production, buyer's purchasing situation, and buyer-supplier relationship characteristics, confirming previous literature that highlight complex and contingent interrelation between investments into buyer-supplier relationships and performance. Going beyond previous research, our study reframes the strategic implementation of SCM from the distinct angle of the economic principle of efficiency. It provides a novel approach of assessing the efficiency of SCM implementation in an analytic way, thus guiding managers in their strategic decision-making regarding the input-output ratio of SCM. Simultaneously, our study adds to SCM theory by conceptualizing strategic SCM as an input-output system with varying transformation efficiencies.

Keywords Supply chain management · data envelopment analysis · DEA · bootstrapped truncated regression · relative efficiency · input-output system

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1. INTRODUCTION

Supply Chain Management (SCM) is increasingly gaining attention both among managers and scholars. Managing their supply chains is a practical necessity for many companies and scholars have extensively investigated the antecedents of SCM practices and their connection with corporate (and also supply chain) performance (e.g., [1][2]). While survey research has also addressed various forms of efficiency, these constructs are usually assessed through rating questions directed towards managers. For example, Gligor et al. [3] measure operational efficiency along the five items of efficiency in managing operational cost, material and inventory costs, wastes in processes and material wastage, transportation and distribution cost, and optimal use of resources, capacity, and time, by means of a seven-point scale that range from “strongly disagree” to “strongly agree”. This means that survey research conceives managers as experts and asks them to evaluate efficiency as a whole or various facets thereof. Such direct evaluation based on intuition and/or backed by data is one way of assessing efficiency. In this paper we propose an alternative approach that calculates the efficiency of SCM implementation in an analytic way; thereby SCM is considered—at a strategic level—as input-output system that transforms various invested resources into various performance dimensions. Such analytic assessment of SCM efficiency has been barely attempted so far, which may be caused by the incommensurability of inputs into and outputs from SCM at the strategic level as well as their complex interrelationship, forbidding simple calculation techniques. Our analytical approach for assessing efficiency resorting to a mathematical programming technique adds to the current state-of-the-art in SCM research and facilitates managerial decision-making as it helps calibrating managerial expert opinion and provides relative efficiency scores, that is, efficiency scores relative to relevant peers. In a second step the study investigates which factors influence these relative efficiency scores, and hence identifies (some of) the conditions under which investments into SCM are costly and/or the benefits from SCM are poor.

In this way our approach offers an alternative view to the currently predominant view in SCM research that various investments into SCM render an increase in performance and may ultimately lead to competitive advantage, for example through cost reduction, increased flexibility and hence customer service, or reduced time-to-market of new products (e.g., [2]). In fact, many studies investigate cause-and-effect relationships between practices and performance (with various mediating and moderating effects); however, they barely zoom into the efficiency of SCM implementation per se (for a notable exception see [4]). We posit that business practice is not only interested in the question whether investments in SCM contribute positively, negatively or not at all to firm performance, but also how "efficient" or "inefficient" SCM actually is. Therefore, the purpose of this study is to draw the attention of SCM scholars towards the analytic investigation of SCM efficiency in comparison to relevant peer organizations. Hence we ask the following research question: How may relative efficiency of SCM implementation be assessed? In response to this question we report the procedure of one possible methodological approach for such investigation and we illustrate the approach by assessing relative SCM efficiencies from the buyer's perspective, based on a data sample of European manufacturing plants. In a second step we identify (facilitating and impeding) factors that are likely to influence these efficiency scores through a regression analysis.

The remainder of the paper is structured as follows. After presenting literature on antecedents (facilitators and impediments) and implications (performance) of SCM, we point to the dearth of studies assessing the efficiency of SCM implementation in an analytic way, and review the use of two-step DEA (Data Envelopment Analysis)-regression approaches in the field of SCM research. Then we describe and discuss the procedure of our proposed methodological approach and link it to our specific empirical application. After reporting the results of the DEA and regression model, we discuss the findings against the background of previous research, and we highlight how the assessment of relative SCM efficiencies through DEA contributes to the academic knowledge base and generates additional insights for managers. The conclusions highlight limitations of the proposed approach as well as the specific empirical application, and point towards directions of future research.

2. LITERATURE REVIEW

After defining core concepts of SCM, performance and efficiency, this section first reviews previous research on facilitators and impediments of SCM and its link to business performance. Then, we show the relative blank of assessments of SCM efficiency and point out why this blank warrants to be filled. Subsequently, we briefly review how our methodological approach for conducting such an efficiency assessment (i.e., two-step DEA-regression) has so far been used, in particular in the field of SCM research. Finally, we review how SCM could be designed as an input-output system at the strategic level.

2.1 Defining core concepts

Although there is generally little consensus regarding the definition of SCM [5], Mentzer et al.'s [6] broad and trans-disciplinary definition provides some common ground. According to Mentzer et al. [6], SCM is defined as "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole" (p.18). Firm performance may be split in operational performance and business performance in the way that measures of operational performance (referring to cost, flexibility, quality, etc.) affect business performance measures such as profit, market share, and customer satisfaction [7]. Finally, based on the common definition of efficiency as the ratio of outputs to inputs, we define SCM efficiency as the ratio of performance dimensions achieved to the resources invested into SCM.

2.2 The traditional cause-and-effect view on SCM, its antecedents and implications

The concept of SCM has often been conceptualized as a triple-jump-model, linking antecedents of SCM to the implementation of SCM practices and these to firm (and also supply chain) performance (e.g., [8]). Antecedents of SCM comprise inter-organisational factors that define the buyer-supplier or overall supply chain relationship as well as organisational factors, often conceived from the perspective of the buying firm. Important inter-organisational antecedents are trust [9], which may be associated with reliability, competence, goodwill (openness and benevolence), vulnerability and loyalty; power (in the form of coercive, expert and referent power); and dependence [10] which may be seen as reciprocal to power [11]. Further inter-organisational factors are reciprocity in forms of mutual benefits as suggested by social exchange theory [8], and relational commitment aiming for long-term partnership and likely entailing sacrifice and important resource investments [12]. Organisational factors influencing the implementation of SCM are for example firm size, which effects positively the engagement into SCM due to the extensive resource and capabilities endowment of larger companies in comparison to smaller ones [13][14]; furthermore, foreign ownership [15][16], and internationality of purchasing [17][18].

Many scholars advocate a positive relationship between SCM implementation (as for example through supply chain collaboration and integration) and firm performance (e.g., [19]); still it is conceded that the suitability of supply chain collaboration and integration needs to be assessed individually [20], for example according to the criteria of strategic relevance and interaction complexity as suggested by [21]. It may be noted at this place that overall empirical evidence for such a link is not entirely clear-cut. Mackelprang et al.'s [22] meta-analysis found a nuanced picture of this link when considering the various dimensions of supply chain integration and the various dimensions of performance (such as financial, market, cost, quality, delivery, flexibility, innovation); the meta-analysis concludes by warning against viewing supply chain integration as universally improving performance (cf. also [23]) and calls for searching for so far undetected moderating variables such as cultural or social issues and process types.

2.3 Efficiency of supply chain management

While cause-and-effect relationships between SCM antecedents, SCM, and performance (including various moderating and mediating effects) are currently in the limelight of empirical research, economic efficiency assessment of SCM implementation itself is largely under-researched. Liang et al. [24] develop DEA-based non-linear programs for measuring supply chain efficiency, and they illustrate their approach in a seller-buyer supply chain context representing either a leader-follower or a cooperative structure. Chen et al. [25] propose an approach for defining a productivity frontier for two-stage processes, where the outputs of the first stage process are the inputs to the second stage process (see also the review by Cook et al. [26]). Saranaga and Moser [27] use value chain DEA approach for estimating the performance of a purchasing and supply management function for several industry sectors. Swink and Zsidison [28] indicate that increased commitment in buyer-supplier relationship only pays off up to a certain point, highlighting negative effects of excessive commitment particularly in relation to costs and profit. Daugherty et al. [29] argue that collaboration only pays off if carefully managed and formalized. Adams et al. [30] point to the crucial role of inter-organizational coordination technologies, mediating supply chain collaboration/integration and performance. Furthermore, Spekman et al. [21] point out that suppliers and SCM strategy need to be carefully chosen and investments in comprehensive (and hence expensive) supply chain collaboration is certainly not warranted in any case. It may be noted that most previous research on SCM implementation and performance largely overlook the question of how "efficient" or "inefficient" SCM is implemented at a strategic level, that is how efficient this management tools transforms various inputs (resources, investments) into outputs (performance); for notable exceptions see Bayraktar et al. [4] assessing the efficiency of SCM and information systems practices and Easton et al. [31] assessing the efficiency of the purchasing process in the petroleum industry. Further related work to efficiency analysis is dealing only with selected supply chain processes, e.g., supplier evaluation [32], manufacturing processes [33], and distribution processes [34].

Such an efficiency assessment can add significant value since it looks at the strategic concept of SCM from a distinct economic angle, and helps managers to assess whether their implementation of SCM is done as resource efficient as it could be. Such an angle that zooms into the concept of SCM itself and calculates SCM efficiencies in an analytic way complements the currently predominant research on the statistical and causal relationships between SCM implementation and performance. In a subsequent step, one may ask which factors influence this efficiency score, which is similar to the currently wide-spread cause-and-effect investigations into the antecedents of SCM.

There is a variety of theoretical angles that could be used for shedding light on why companies work together in a supply chain and how effective SCM actually is. When bilateral dependency builds up, transaction cost economics suggests supply chain partnership as hybrid mode of governance situated between market and hierarchy [35]. Similarly, resource-dependency theory explains engagement in SCM with the need of accessing crucial resources that are held by other organizations [36]. Regarding the question how firms strategize on a firm, dyad, and supply chain level, and whether SCM is effective, the resource-based view (RBV) [37] and its extension towards the relational view of strategic management [38] provide important insights. For example, Gold et al. [39] conceptualize supply chain collaboration on sustainability issues as a possible catalyst of valuable inter-organizational resources that may lead to competitive advantage. Referring to network theory

[40], the position of an organization within its network determines the accessibility of partners and their resources, and hence may affect the benefits that accrue to an organization from supply chain collaboration [38]. These theoretical angles (amongst others) have been rather widely used by SCM scholars in order to explain why companies engage in SCM, and how SCM links to competitive advantage and business performance.

However, these theories do not seem to be conclusive on the question of how efficient the implementation of SCM actually is. For example, an inter-organizational resource such as joint learning in buyer-supplier relationships may be valuable, rare, and hard to imitate and substitute by competitors, and thus could be regarded a source of competitive advantage [41]. This does not say much though about how costly it was to develop and maintain this resource, and what benefits it provides to the company in return. To fill this gap, we propose DEA as an approach for investigating the efficiency of SCM implementation, which prepares and enables a follow-up in-depth analysis of related SCM processes.

2.4 Applications of DEA-regression approaches

Two-step DEA-regression approaches (cf. e.g., [42]) are suitable for tackling these questions. DEA has been applied mainly in the fields of banking, healthcare, logistics, agriculture and farming, transportation, and education [43][44][45]. In the field of transportation, DEA was used for examining the performance of airlines, airports, airport authorities as well as railway and bus systems [43]. Barros and Dieke [46] and Gillen and Lall [47] adopt the combined two-step DEA-regression approach for finding factors influencing the efficiency of airports. Liu et al. [43] note that the two-step DEA-regression approach is generally gaining importance and can particularly be considered a trend in agricultural research. Although DEA is a popular method with diverse applications in the broad field of business research and has also been applied to the fields of transportation and logistics as well as purchasing and supply chain management, this method has so far not been used for assessing the efficiency of SCM implementation. In the subsequent sub-section we will describe our specific approach towards such assessment.

2.5 Conceptualizing SCM as input-output system

In the current paper, we conceive SCM as a system that is fed by various inputs and generates various outputs for the buyer. Inputs consume company resources in some way, while outputs represent the gains from SCM. Thereby the transformation of inputs into outputs is not further specified, i.e. remains a “black box”. Generally speaking, SCM as a system could be operationalized on an operational and process level [48], on a functional level [31], or on a comprehensive strategic level, as was attempted in the extent paper. Concerning inputs, a variety of parameters could be considered that represent “expenses” in a broad sense and may comprise leadership, strategic purchasing, advanced planning systems, intra- and inter-organizational relationship building, information sharing, knowledge building, integration of logistics and operations, adaptation of product development and marketing, supply and distribution network structure etc. (e.g., [5][49][50][51][52]). Thereby SCM could be conceived very broadly as a system that absorbs the inputs (of all supply chain actors involved or specific actors) and transforms them into benefits for these actors. According to the initial definition of system boundaries, outputs of SCM may be assessed on various levels, e.g., on a plant, firm, or supply chain level. Although several studies have advocated seizing overarching supply chain performance (e.g., [53][54][55]), empirical studies still predominantly measure performance from the perspective of one supply chain actor, often the buying company. Chen and Paulraj [49] for example, split buyer’s performance into financial (e.g., return on investment, firm’s net income before tax) and operational performance (e.g., cost, quality, dependability, flexibility, speed). The extant empirical application presented in this paper defines the boundaries of SCM rather narrowly for reasons of data availability, joining input factors rather closely to the buyer-supplier interface and assessing output factors from the distinct perspective of the buying company.

The effectiveness of SCM, and related to this the efficiency scores calculated through the conceptualisation of SCM as input-output system, could then be seen as caused by various factors. These antecedents of SCM effectiveness and efficiency, when perceived from the buyer’s angle, refer basically to the buying plant’s characteristics such as size [13][14], industry [56], national culture [57], or foreign ownership [15][16]; the quality of its relationships with suppliers and customers [8][9][58]; characteristics of product portfolio [59][60]; supply chain roles such as the roles of manufacturer, distributor, retailer and service provider [51]; degree of innovativeness such as number of newly introduced products and product development speed [58][61]; type of supply chain, i.e. manufacturing versus service supply chains [62]; specific risks and chances from global sourcing [63]; perceived vulnerability of buyer [64]; buyer’s strategic situation in particular regarding its supply and distribution channels [65]. Within the subsequent methodology section, we link our selection of input and output parameters as well as antecedents more specifically to previous literature, thus justifying their choice while acknowledging existing limitations of our empirical approach.

3. METHODOLOGY

3.1 Data Envelopment Analysis as tool for assessing SCM efficiency

Data Envelopment Analysis (DEA) is a mathematical programming technique that determines relative efficiencies of Decision Making Units (DMUs) against an efficiency frontier which is defined by the most efficient peers. DEA is suitable for benchmarking performance [66] of any system even if inputs and outputs are incommensurate due to different measurement units [67] as long as DMUs are comparable among each other. Dyson et al. [68] specify different criteria that should be considered in terms of homogeneity, e.g., DMUs have to undertake similar activities such as manufacturing. Based on the fact that DEA allows for aggregate comparison at the strategic level, the modelling of the sub-processes of different manufacturing companies is not required [69]. Therefore, DEA is of high relevance for SCM efficiency analysis at the strategic level, i.e., to identify the most competitive DMUs that may serve as benchmark for less efficient units. Thereby, Dyson et al. [68] state that differences between the DMUs are naturally of interest for DEA, e.g., typical strategic decisions such as different technologies used by the DMUs.

In their seminal paper, Charnes et al. [70] proposed that the efficiency score of any DMU is obtained "as the maximum of a ratio of weighted outputs to weighted inputs subject to the condition that the similar ratios for every DMU be less than or equal to unity" (p.430). Another alternative could be to start with the output and to look at the ratio of input to output [71]. This may be formulated as,

$$\max_{\lambda_j,\theta,s_i^+,s_r^-} \quad \varphi + \left(\sum_{i=1}^{m} s_i^+ + \sum_{r=1}^{s} s_r^- \right)$$

s.t.

$$\begin{aligned} &\sum_{j=1}^{n} X_j \lambda_j + s_i^+ = x_{i0}, && \forall\, i = 1, \cdots, m \\ &\sum_{j=1}^{n} Y_j \lambda_j - s_r^- = \varphi y_{r0}, && \forall\, r = 1, \cdots, s \\ &\lambda_j \ge 0, && \forall\, j \end{aligned} \tag{1}$$

where φ is the efficiency score for DMU_O;

y_{r0} is the output r generated by DMU_O; x_{i0} is the input i used by DMU_O;

$X_j = (x_{1j}, x_{2j}, \ldots, x_{mj})$ is the vector of actual inputs used by DMU_O;

$Y_j = (y_{1j}, y_{2j}, \ldots, y_{sj})$ is the vector of actual outputs generated by DMU_O;

s_i^+ is the amount of slack in input i for DMU_O; s_r^- is the amount of slack in output r for DMU_O. λ_j is the dual multiplier; j = 1, …, n is the number of DMU; i = 1, …, m is the number of input

and r = 1, …, s is the number of output.

As one distinct advantage, DEA can be applied even if it is unknown how exactly inputs are transformed into outputs [44]. As well, DEA does not require the analyst to know relative weights of input and output variables or subjectively attribute those weights [72].

3.2 Empirical application: Data

For investigating SCM efficiency and its antecedents by two-step DEA-regression, we use data from the Global Manufacturing Research Group (GMRG), an association of international scholars. GMRG has collected data from manufacturing plants in numerous countries since 1985 (www.gmrg.org) through standardized questionnaires, of which items and measurements have been continuously improved in annual meetings. This concerted endeavour as well as rigorous translation and back-translation between English and local languages allow for data pooling [73][74]. For our analysis, we use data of the fourth round of the GMRG survey, which was gathered between 2006 and 2009. The survey targeted plant managers (as key informants) who are experts in terms of their manufacturing plant's processes and operations.

We first selected those EU-EFTA countries, for which data from three GMRG questionnaires were available, covering a set of variables for both DEA and subsequent regression analysis; then we excluded listwise all plants for which data for one or more of our variables were missing. This procedure was hence driven by data availability and resulted in a sample size of 164 plants spread over seven European countries, namely Austria (8), Germany (53), Ireland (33), Italy (33), Sweden (22), and Switzerland (15). It may be noted that the selection of variables for both DEA and regression analysis was conducted on theoretical grounds as explained below, but was restricted by actual availability of data. Empirical follow-up analyses may operationalise input and output factors (hence SCM efficiency) as well as factors driving and impeding SCM efficiency in more specific and/or more comprehensive ways.

3.3 Empirical application: DEA

We transfer the application of DEA from organisations to the rather intangible concept of corporate SCM implementation which we conceive as an input-output system that is to be optimized, against the benchmarks of relevant peers. For assessing the efficiency of SCM, we conceive SCM as a system that is fed by various inputs and generates various outputs for the buyer. Inputs all represent expenses in a broad sense, while outputs represent benefits from SCM practices for the buyer. Due to a limited scope of constructs with sufficient data available, the supply chain focus of this study mainly pertains to the buyer-supplier interface and benefits are measured from the perspective of the buyer only. Future studies may look more broadly at multiple tiers of the supply chain and measure output from an overarching supply chain point of view (cf. [53][54][55]). Input and output variables are measured by Likert scales (cf. [75]). Table 1 lists the 4 input variables and 5 output variables used for the DEA model; the number of variables to be included in the DEA was well within the rule of thumb given a sample size of 164 [68].

Input variables comprise buyer sponsored supplier conferences, supplier representatives in plants, formal supplier development programs and top management support of purchasing. They are all linked to supplier-buyer integration and buyer performance but represent major expenses, in terms of invested organisational resources.

Buyer sponsored supplier conferences refer to meetings with suppliers that clarify mutual expectations and reflect on how to develop the buyer-supplier relationship, and have been found to contribute to supplier-buyer integration and performance [50][57][76]. *Supplier representatives in plants* may be conceived as boundary spanners that can be integrated in cross-functional teams thus increasing communication and knowledge sharing, ultimately leading to enhanced risk management, product and process innovation, and customer value [57][77][78]. *Formal supplier development programs* are strategic activities of buying companies to ensure that the suppliers meet their expectations regarding product quality and other performance criteria, thus contributing to the performance of the buying company and ideally of the entire supply chain [79][80][81]. *Top management support of purchasing* that ensures access to organisational resources helps strengthening the overall strategic role of purchasing and supply management, and was found to contribute substantially to all performance dimensions including social and environmental sustainability [49][82][83].

We measure the output of SCM by a variety of operational performance measures such as product cost, product quality, dependability (delivery as promised), flexibility, and new product design time [49][84][85]. Operational performance indicators are more likely to measure the immediate benefits by SCM implementation, in contrast to financial performance indicators such as market share that are more likely to be influenced by factors external to firms and supply chains [49]

Table 1: Input and output variables of DEA

Variable	Type of variable	Description	Unit	Refer-ence
Buyer sponsored supplier conferences (SSC)	Input	To what extent do SSC contribute to the organization's competitive goals?	Likert scale from 1 (no extent) to 7 (a great extent)	[50][57]
Supplier representatives in plant (SR)	Input	To what extent do SR contribute to the organization's competitive goals?	Likert scale from 1 (no extent) to 7 (a great extent)	[57][77][78]
Formal supplier development program (SDP)	Input	To what extent do SDP contribute to the organization's competitive goals?	Likert scale from 1 (no extent) to 7 (a great extent)	[79][80][81]
Top management support of purchasing	Input	To what degree does top management support the strategic importance of purchasing by providing adequate financial resources?	Likert scale from 1 (no extent) to 7 (a great extent)	[49][82][83]
Total product costs (C)	Output	Plant's performance compared with competitors regarding C	Likert scale from 1 (far worse) to 7 (far better)	[49][84][85]
Perceived overall product quality (Q)	Output	Plant's performance compared with competitors regarding Q	Likert scale from 1 (far worse) to 7 (far better)	
Delivery as promised (D)	Output	Plant's performance compared with competitors regarding D	Likert scale from 1 (far worse) to 7 (far better)	
Delivery flexibility (F)	Output	Plant's performance compared with competitors regarding F	Likert scale from 1 (far worse) to 7 (far better)	
New product design time (N)	Output	Plant's performance compared with competitors regarding N	Likert scale from 1 (far worse) to 7 (far better)	

Since all input and output variables are measured on a seven-point Likert scale, we assume constant returns to scale, that is Charnes et al.'s [70] so-called CCR model, named according to the surname initials of the authors Charnes, Cooper, and Rhodes. We do not impose any weight restrictions on input and output variables; hence DEA attributes freely weights to the variables as determined by equation (1).

3.4 Empirical application: Subsequent regression analysis

Following from the results of the DEA, we explore factors fostering or impeding SCM efficiency based on a regression model. When using the DEA efficiency scores as outcome variable of regression models, these scores cause problems as they are non-parametric and serially correlated "in an unknown and complicated way" (p.415) [86]. In addition, the DEA scores of our output-oriented model represent a data set censored left at the value 1; this means that the DEA scores never go below 1. Despite the consensus regarding the specificities of DEA scores as outcome variable of subsequent regression analysis, there is a lack of consensus regarding which approach to take in a second stage regression.

Based on a comparison of four second stage regression approaches Hoff [87] concludes that "the tobit model, or even OLS, may be sufficient for modelling DEA scores against exogenous variables" (p.434) [87], while she discourages the use of inflated beta models. Simar and Wilson [88][89] criticize these conclusions and recommend the use of bootstrap methods instead; again, the benefits of Simar and Wilson's [89] proposed procedure are largely contested by Friesner et al. [86] who suggest that Simar and Wilson's [88][89] bootstrapped truncated regression approach only generates small improvements in second stage estimates. Despite this ongoing academic debate, it appears to be unequivocal in literature that the bootstrapped truncated regression generates better results than other commonly applied techniques such as Tobit models or OLS. For this reason, we have chosen to use the second bootstrapped truncated regression algorithm proposed by Simar and Wilson [88], as implemented in the rDEA package for R [90].

In this method, the DEA scores are first calculated as usual, and used as the dependent variable in a truncated regression with the environmental variables as the independent variables, estimated using the method of maximum likelihood. The regression coefficients and error variances from this stage are then used in a parametric bootstrap to estimate the bias in each DEA estimate. These bias estimates are then used to construct bias-corrected DEA estimates from the original DEA estimates. These bias-corrected DEA estimates are then once again used to estimate a truncated regression model with the bias-corrected DEA estimates as the outcome variable, and the environmental variables as the predictor variables. Finally, another parametric bootstrap is used to produce bootstrapped confidence intervals for the regression coefficients for the final regression model.

Our regression model assumes that efficiency in SCM depends on plant's characteristics such as number of employees [13][14], ratio of foreign ownership [15][16], country, i.e. national culture [57]; characteristics of production such as diversity of production [59][60] and the number of newly introduced products [58][61]; buyer's purchasing situation encompassing the importance of purchasing (i.e. the ratio of costs for purchased material against overall manufacturing cost) [64] and ratio of internationally purchased material [63]; and characteristics of buyer-supplier relationship such as information asymmetry in supplier evaluation [91][92] and conflict settlement [93]. We acknowledge that there are further variables that could have an impact on SCM efficiency and/or could have been controlled for—as outlined in the literature review—that we could not include in our empirical model due to the restrictions imposed by the truncated nature of our dependent variable and the number of observations.

The model specification for the truncated regression is:

$$DEA^{*}_{i} = B_1 + B_2 NE_i + B_3 PO_i + B_4 DP_i + B_5 NP_i + B_6 IMP_i + B_7 INP_i + B_8 IA_i + B_9 CS_i + B_{10} GE_i + u_i \quad (2)$$

As the efficiency score DEA_i is obtained by mathematical optimization as outlined by formula (1), we define a transformed variable DEA^{*}_{i} as outcome variable of the truncated regression. DEA^{*}_{i} represents the virtual plant efficiency taking into account that efficiency scores (DEA^{*}_{i}) feature a left-hand limit at 1, which denominates most efficient plants (i.e. plants on the efficiency frontier):

$$DEA_i = 1 \text{ if } DEA^{*}_{i} \leq 1 \quad (3)$$

$$DEA_i = DEA^{*}_{i} \text{ if } DEA^{*}_{i} > 1 \quad (4)$$

where i = 1, …, n is the number of plants;

DEA^{*}_{i} = virtual plant efficiency;

DEA_i = calculated plant efficiency

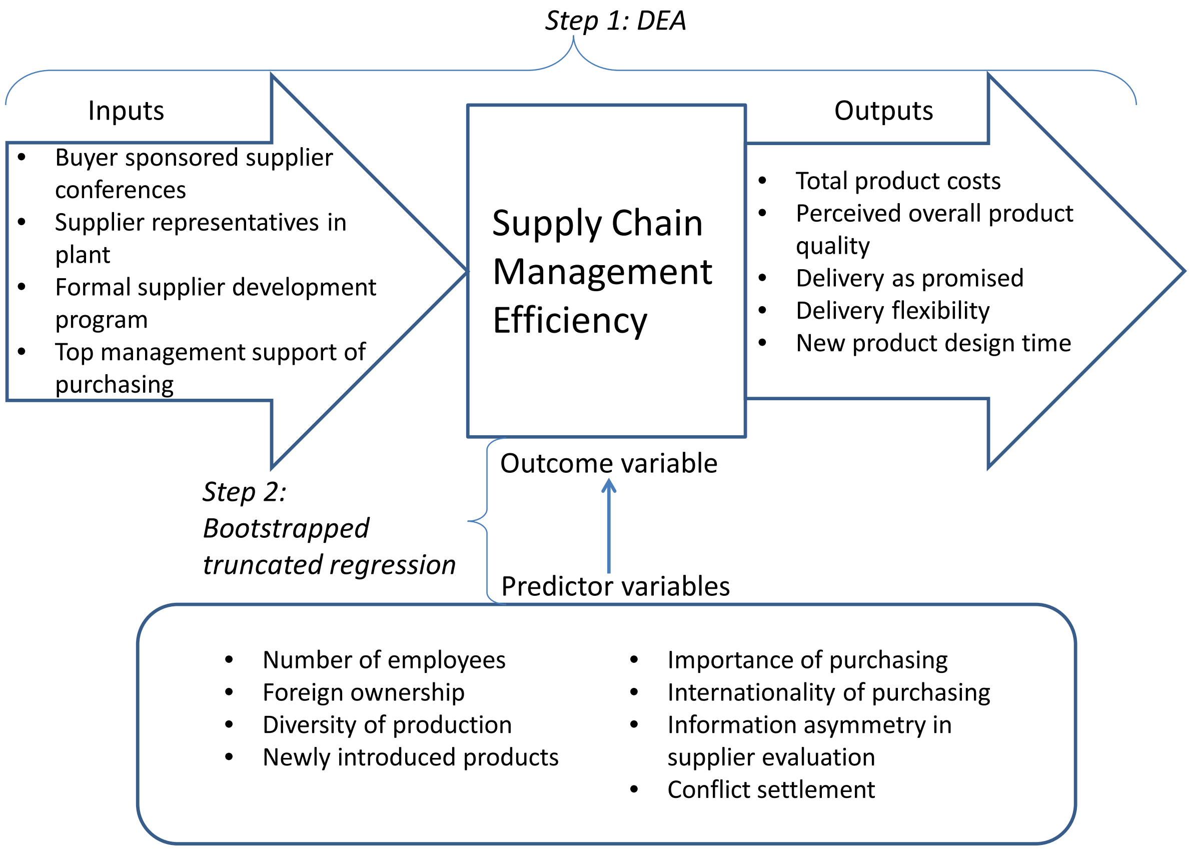
Table 2 presents and describes the outcome variable as well as the predictor variables.

Table 2: Predictor and outcome variables for the bootstrapped truncated regression

Variables	Label	Type of variable	Description	Unit	Reference
DEA score	DEA	Outcome	The DEA score assessing the plant's SCM efficiency	1, …, ∞	
			Control variable		
Country	GE	Predictor	Germany as location of the plant (dummy variable)	0 or 1	[57]
			Plant's characteristics		
Number of employees	NE	Predictor	Approximately how many total employees work for the plant?	Employees	[13][14]
Foreign ownership	PO	Predictor	What percent of the plant ownership is international?	%	[15][16]
			Characteristics of production		
Diversity of production	DP	Predictor	How many product lines or product families does the plant produce?	Product lines or product families	[59][60]
Newly introduced products	NP	Predictor	What percent of plant sales is currently from products that have been introduced in the last two years?	%	[58][61]
			Buyer's purchasing situation		
Importance of purchasing	IMP	Predictor	About what percent of the plant's total manufacturing cost is for material?	%	[64]
Internationality of purchasing	INP	Predictor	What percent of your plant material costs are purchased from international sources?	%	[63]
			Characteristics of buyer-supplier relationship		
Information asymmetry in supplier evaluation	IA	Predictor	Please indicate the degree to which you agree with the following statements in relation to your most important supplier: It is easy to determine the performance of this supplier.	Likert scale from 1 (completely agree) to 4 (completely disagree)	[91][92]
Conflict settlement	CS	Predictor	Please indicate the degree to which you agree with the following statements in relation to your most important supplier: This supplier and my firm have developed a standard approach to solving problems when they arise.	Likert scale from 1 (completely agree) to 4 (completely disagree)	[93]

Figure 1 presents the complete research model, which uses, in a first step, DEA for assessing relative SCM efficiency and, in a second step, bootstrapped truncated regression analysis for investigating driving and impeding factors for SCM efficiency scores.

Figure 1: Research model



4. RESULTS

The DEA results in an average efficiency score of 2.02 and altogether 34 maximum efficient plants (i.e., plants with DEA scores equal to 1). Table 3 gives an overview of the distribution of DEA scores. The higher the DEA score, the more inefficient is the plant. Table 4 provides additional information on the 34 maximum efficient plants in terms of country and industry sector. It highlights which countries and industry sectors are situated at the productivity frontier, in absolute numbers and relative to their occurrence within our sample.

Table 3: Classification of inefficiencies by DEA

Range	Number of plants
DEA = 1	34
1 < DEA <= 2	74
2 < DEA <= 3	28
3 < DEA <= 4	14
4 < DEA <= 5	6
5 < DEA <= 6	4
6 < DEA <= 7	3
DEA > 7	1

Table 4: Descriptive statistics of maximum efficient plants (DEA =1)

Country	Absolute	Relative	Industry sector	Absolute	Relative
Austria	3	0.38	Printing, publishing, and allied industries	2	0.67
Germany	12	0.23	Electronic and other electrical equipment and components, except computer equipment	6	0.35
Sweden	5	0.23	Manufacture of motor vehicles, trailers and semi-trailers	1	0.33
			Manufacture of other transport equipment	1	0.33
Switzerland	3	0.20	Textile mill products	1	0.25
Ireland	6	0.18	Primary metal industries	1	0.25
Italy	5	0.15	Paper and allied products,	1	0.25
			Fabricated metal products, except machinery and transportation equipment	7	0.21
			Chemicals and allied products	1	0.20
			Rubber and miscellaneous plastics products	2	0.20
			Industrial and commercial machinery and computer equipment	7	0.19
			Food and kindred products	2	0.18
			Measuring, analysing, and controlling instruments; photographic, medical and optical goods; watches and clocks	1	0.09
			Miscellaneous manufacturing industries	1	0.08
			Lumber and wood products, except furniture	0	0
			Furniture and fixtures	0	0
			Leather and leather products	0	0
			Stone, clay, glass, and concrete products	0	0

The bootstrapped truncated regression model (see Table 5) shows how predictor variables explain inefficiencies of plants. This means that a positive coefficient specifies that predictor variables contribute to inefficiencies, whereas a negative coefficient defines that predictors reduce inefficiencies, i.e. plants move towards their efficiency frontier. The model indicates that the number of employees and foreign ownership are positively linked to SCM inefficiency. Country affiliation, diversity of production, newly introduced products, importance of purchasing, degree of purchasing from international sources, and standardized conflict settlement are negatively linked to SCM inefficiency. This means that these variables increase the efficiency of SCM implementation of plants and bring them closer to the efficiency frontier. Buyer-supplier information asymmetry does not have significant impacts. The truncated regression model was tested for goodness of fit by a likelihood ratio test; a highly significant result for this test indicates that the inclusion of the predictor variables significantly improves the model.

Table 5: Results of bootstrapped truncated regression

Variables	Coefficient
Constant	-41.822065 ***
Country (Germany)	-19.2227***
Number of employees	0.005128+
Foreign ownership	55.531578***
Diversity of production	-0.072883***
Newly introduced products	-3.232185**
Importance of purchasing	-52.011556***
Internationality of purchasing	-51.514951***
Information asymmetry in supplier evaluation	-2.833392
Conflict settlement	-6.583710**

Note: ***p<.001; **p<.01; *p<.05; $^{+}$p<0.1

5. DISCUSSIONS

This section first presents the findings of our empirical illustration in the light of previous research, also considering related managerial implications. Then, our proposed approach of conceiving SCM efficiency at a strategic level as an input-output system to be assessed by DEA is discussed regarding its novelty and usefulness for scholars and managers.

Our analysis suggests that country affiliation, the characteristics of manufacturing plants, characteristics of production, buyer's purchasing situation, and the characteristics of buyer-supplier relationship influence SCM efficiency. Given the differences in SCM implementation induced by national cultural [57], it is little astonishing that SCM efficiency appears to be influenced by the country the plant is located in. In terms of the characteristics of manufacturing plants, the size of a manufacturing plant (number of employees) is linked at a low significance level to inefficiencies in SCM. This is somewhat in contrast to earlier findings that firm size facilitates SCM due to large firms' crucial resource and capability endowment [14]. In fact, it might be true that larger firms are more prone to engage in SCM activities; this does not necessarily mean, however, that SCM is carried out in a particularly efficient way by larger firms. We suggest that managers keep a wary eye on inefficiencies that might be linked to bureaucratic slack or additional costs of intra-organizational cross-functional collaboration and integration, which may increase with the size of the plant or organisation, respectively.

Furthermore, our analysis finds some evidence that foreign plant ownership makes SCM inefficient. Foreign ownership has been connected to the availability of extensive (financial and other) resources which may be used to engage in supplier development, relationship building, and SCM in general [13][15][16]. This does not imply however that SCM itself is carried out efficiently by foreign-owned plants. On the contrary, it seems that cultural misconceptions [94] between owners, management and employees may create frictions that tend to turn SCM practices by foreign-owned firms rather inefficient. This argument may be used for cautioning managers about engaging too hastily in international mergers and acquisitions. For further exploring this issue, the efficiency of SCM implementation may be investigated contingent for example on the degree of international ownership, cultural difference, and date of merger or acquisition.

According to our analysis, diversity of production—operationalized as the number of product lines or product families produced in the plant—appears to contribute to SCM efficiency. This might be explained by the need of those plants to develop a greater degree of professionalization, formalization and technological support of purchasing and supply chain management for example through e-purchasing, relational technologies, and standardized supplier evaluation [29][30][95]. At the same time, a high ratio of plant sales from products that have been introduced in the preceding two years is also linked to SCM efficiency.

In terms of buyer's purchasing situation, we find that the importance of purchasing, i.e. the ratio of a plant's material cost to all manufacturing cost, as well as the degree of purchasing from international sources increases SCM efficiency. Beneficial effects of international purchasing are in line with Mol et al. [18] who argue that international sourcing allows for selecting world-class suppliers while minimizing costs. Although still debated, there is rather strong support for the view that international purchasing contributes to the purchasing firm's performance; Quintens et al. [96] mention in their literature review the following benefits (among others): high product quality, better delivery, access to world-class technology, more satisfying supplier-buyer relationships. Related costs for example regarding transportation and handling, administration, customs, and additional global risks of damage and supply disruption appear to be only secondary [97]. It may however be noted that in particular the costs of transportation and warehousing would gain weight when assessing performance more comprehensively on the triple bottom line (social, environmental, and economic performance) [98] and when extending performance assessment beyond the single company for comprehending (at least parts of) the supply chain [99][100].

Regarding the characteristics of buyer-supplier relationship, an established approach to solve problems between supplier and buyer contributes to efficiency of SCM implementation; in contrast, we cannot find a statistically significant link between information symmetry in supplier evaluation and SCM efficiency. Previous research has conceived inter-organisational aspects as key antecedents of SCM. Factors such as trust, reciprocity and common codes are generally considered to be the grease that facilitates buyer-supplier relationships (e.g., [8][9][10]); moreover, collaborative relationships have been often linked to improved performance, backed by the arguments of risk management and mitigation [101], access to required external resources [102] and synergetic effects of complementary resources and capabilities [103]. On the other hand, literature points to the fact that supply chain partnerships often do not yield the expected benefits [104]. In fact, developing buyer-supplier relationships requires high degrees of commitment and investment from all parties involved [21]; these investments may (over-)compensate for improved performance outcomes [28]. Here a limitation of our research design appears, namely the dearth of indicators for relationship quality. Future studies may exactly focus on these aspects (i.e., trust, mutuality, common language, personal ties) for evaluating the link between relationship quality and SCM efficiency in a broader and deeper way.

Summing up, we argue that SCM should not be implemented without considering its benefits against the expenses, put on both sides of the scales. The overall efficiency of SCM depends on a careful choice of supply chain strategy [21][65], partner selection, inter-organizational synergies [104], and clear objectives and standards [29]. We call for a more economically aware approach towards assessing the benefits of SCM implementation, including various forms of "efficiency analysis". The popular phrasing of "investing into relationships" too easily may blur the view and soothe the heart of managers regarding which returns on investment are to be expected at which point of time. It is clear that investments in SCM that do not feature positive net present value weaken the overall competitive position of the company.

Our proposed methodological approach represents a novel way of conceiving and assessing relative SCM efficiency at a strategic level. It focusses on the question of how efficient SCM endeavours are, which has been neglected by previous research that predominantly investigated cause-and-effect relationships between antecedents, SCM practices and firm/supply chain performance. In this way, the conceptualisation of SCM efficiency as input-output system and DEA as mathematical programming technique to assess relative SCM efficiencies, open up new fields of enquiry for SCM academics. At the same time, conceptualisation and related technique encourage managers to re-assess the overall benefit of their plants' specific implementation of SCM, and for this end, represent a valuable analytic tool to compare their plants' efficiency of SCM implementation at a strategic level with that of their peers. In this way our paper responds to Ferdows et al. [105] who claim that operations management literature is not sufficiently dealing with the growing complexity and opportunities of supply chain networks, so that research could be of direct guidance for managerial decision-making. Consequently, it is necessary to develop new quantitative tools and approaches for managers. In this respect, the presented approach of conceptualising and assessing SCM efficiency at the strategic level might contribute to enriching managers' analytic toolkit and improve SCM related decision-making. Yang et al. [106] underline as well that DEA is suitable for the evaluation of competitive strategy and efficiency. The presented novel approach helps investigating factors driving SCM efficiency at the strategic level, so to systematically deal with the related complexities in supply chains. DMUs compete with each other to maximize their DEA efficiency score; thereby, the competitiveness efficient frontier is the minimal curve containing all current positions in an industry [107].

6. CONCLUSIONS

This study reframes the implementation of the popular management concept of SCM from the angle of the economic principle of efficiency, which has been neglected in scholarly literature so far. This has implications for management practice and SCM theory.

On a managerial side, it may be concluded that strategy and specific orientation (goals, partners, formalization, synergies, risk levels) need to be carefully accounted for when implementing SCM; otherwise the implementation of SCM may turn out to be overly costly while rendering mediocre benefits. In this way, the study reminds managers to be alert and critical when investing in SCM and when appraising these investments; the view of SCM as a strategic means to some (often vague) long-term goals would profit from being complemented by a more operational view on SCM focusing on its efficiency (understood as ratio of outputs and inputs). In this way, managers may monitor the accrued benefits from their investments into SCM along different points in time, and then have a more in-depth look into the processes and contingency factors that impact on the efficiency level of their SCM implementation.

On an academic side, the commonly assumed link between engaging in SCM practices and enhanced performance often misses to acknowledge the level of related inputs (i.e., costs, investments, resources of all kind) that is necessary for implementing the specific SCM activities. Therefore, SCM scholars may direct their attention towards the need of developing theory that allows differentiated insights into when (and when not) and how SCM implementation is overall beneficial to a company (and its supply chain) from a cost-benefit perspective. Such a distinct focus on SCM efficiency complements the existing body of knowledge that focusses on the reasons why companies engage in SCM, and on the cause-and-effect relationships between SCM antecedents, SCM, and competitive advantage, under consideration of various mediating and moderating variables.

Still, the proposed conceptual and methodological approach does not go without limitations. On the methodological side, it may be highlighted that DEA does not model the processes in detail, i.e. it remains unobserved how inputs are actually transformed into outputs. While this shortcoming applies for all DEA approaches, it may be even more striking when considering a highly abstract concept such as SCM at a strategic level. Further analysis would be necessary to understand the implications of the results provided by the strategic SCM efficiency analysis at a tactical and operational level. For this end, tools such as the supply-chain operations reference (SCOR) model may help breaking supply chain business processes down to single activities and their components, while providing a hierarchical performance measurement system that facilitates understanding and hence improving SCM efficiency.

In addition, the empirical application for illustrating our conceptual and methodological approach faces some substantial shortcomings, in particular regarding the specific operationalisation and assessment of relative SCM efficiency as input-output system, which was restricted by data availability. Furthermore, data from the fourth round of the GMRG survey, gathered from 2006 to 2009, was used, which needs to be accounted for when interpreting and drawing conclusions from the results. Despite these limitations, the empirical part of the paper clearly helps demonstrating our approach and facilitates its replicability as well as critical assessment and discussion in future research.

Regarding follow-up research, it might be of particular interest to investigate in more details under which conditions (in terms of external business environment as well as internal company and supply chain strategies) and according to which pattern investments into supplier-buyer relationship are likely to pay off. Are aspects such as trust, reciprocity, common codes overrated academic and consultancy fads which lure companies into inefficient business practice or are they drivers of efficiency for certain strategic options? Furthermore, it might be promising to assess how various types of buyer-supplier power relations [108] and purchasing situations [109] influence the efficiency of SCM implementation. Here, the buyer's perspective on SCM efficiency could be matched with the supplier's perspective on demand chain management efficiency. Moreover, the proposed approach of calculating relative SCM efficiency via DEA would warrant further critical methodological discussion as well as empirical application in order to assess its usefulness. In addition, SCM efficiency assessment through DEA would need to be followed up by business process analyses that help understanding low efficiency levels and finding leverage points to improve these levels. Finally, the complex construct of SCM efficiency may be assessed empirically by more specific and/or comprehensive sets of input and output parameters so to better grasp its essence. Thereby our conceptual perspective on SCM efficiency on a strategic level as an input-output system needs to be further assessed for its validity and applicability by follow-up research.

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