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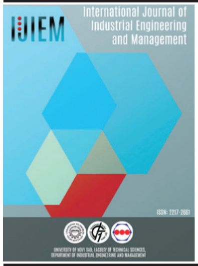

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Original research article

Perceptions of barriers to the implementation of circular economy initiatives in Central European manufacturing companies

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ABSTRACT

This paper examines the relationship between perceived barriers to Circular Economy (CE) initiatives and the specific characteristics of manufacturing companies. The study uses data from a sample of 241 manufacturing companies located in the Central European countries of Slovakia and Slovenia. Data collected as part of the European Manufacturing Survey was analysed with ordered logit regression models to examine the perception of seven commonly mentioned CE barriers. Our results show a significant relationship between the perception of CE barriers in manufacturing companies and their size, nationality, profitability, product/production characteristics, CE motives and use of CE technologies. Companies with higher profitability were found to be more likely to minimize the significance of CE barriers, while companies with experience of implementing CE technologies (especially remanufacturing) are more likely to perceive most CE barriers. The findings corroborate the conclusions of other studies which have addressed the issue of barriers to innovation. The results of this study can contribute to the creation of better CE policies and practices that consider company-specific features and contextual factors, thereby supporting a more effective approach to CE implementation in manufacturing companies.

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1. Introduction

Recent years have seen a growing interest in the issues of sustainability and Circular Economy (CE) practices in manufacturing industries among researchers and practitioners [1], with several studies focusing on the concept of CE in manufacturing in general (e.g., [2]-[4]) and in specific manufacturing sectors (e.g., [5]-[8]). These studies offer different viewpoints on various issues such as Industry 4.0 (see [9]), but the majority also address the issue of barri-

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ers to the implementation of CE measures. Barriers to CE implementation can be understood as any impediment, either technical or financial, or any bottleneck, either regulatory or cultural, that can obstruct the transition towards CE [10].

Over the past fifteen years, research on the topic has identified, categorized and analysed various barriers which can hinder the full adoption of CE principles. Some studies have listed the barriers which are faced by manufacturing industries (e.g., [3], [11], [12]), different economic sectors (e.g. [7], [13]) and SMEs (e.g. [14]), while other research (e.g. [15]-[19]) has attempted to categorise and classify different obstacles, such as the study by Kirchherr et al. [19] which attributes the slow progress in CE adoption within the EU to cultural, regulatory, market and technological barriers. In contrast, other studies (e.g., [20]-[22]) have drawn a distinction between internal and external barriers. Another interesting line of research has attempted to delineate the relevancy and frequency of CE barriers in the context of individual companies or their relationship with specific company characteristics (such as industry type, product focus, technological state and company size); for example, Matsumoto et al. [23] highlight the fact that many companies are hesitant to integrate remanufacturing into their corporate strategies due to concerns about customer acceptance, a barrier which is closely associated with industry-specific factors and product characteristics. Trianni et al. [24] examined CE barriers in metalworking SMEs and concluded that company size can be linked to the perception of CE barriers.

As Bjørnbet et al. [2] have recently shown, research into CE in the manufacturing sector has evolved from purely conceptual studies to more empirical research (e.g., [25]-[27]) as the implementation of CE programs become more commonplace. Our research continues in this empirical vein by investigating the relationship between perceptions of CE barriers and the specific characteristics of manufacturing companies, including use of CE technologies, to eliminate gaps in our knowledge on this topic.

Despite the growing number of studies addressing CE barriers in specific contexts, such as countries, industries (e.g., [11], [28]-[30]), production and product characteristics (e.g., [11], [29]), company age (e.g., [31]), company size (e.g. [24]), profitability levels and the scope of R&D activities, much of the research conducted to date has neglected the issue of how these characteristics influence the perception of barriers. The lack of studies on CE barriers in Central European countries also remains evident despite recent discussions on sustainability issues in manufacturing within the region (e.g., [32], [33]).

As will be outlined in the next section, various approaches can be adopted to the issue of CE barriers, ranging from identification, classification or grouping studies to research which places a more specific focus on relationships with other variables. Our study falls under the latter category as it aims to shed light on the impact of various barriers to CE implementation and their relationships with the specific characteristics and attributes of manufacturing companies. With the aim of addressing the literature gaps which we have identified on CE barriers and based on the specific focus of our study, we posit the following research questions (RQ):

RQ1: To what extent are the perceptions of barriers to CE implementation determined by specific industries, production/product characteristics, the scope of R&D activities and profitability levels?
RQ2: To what extent are the perceptions of barriers to CE implementation determined by the existing use of CE technologies?
RQ3: To what extent are the perceptions of barriers to CE implementation determined by company attributes such as size, year of establishment and nationality?

The study opens with an overview of previous and related research in the field in Section 2 followed by a methodology section which outlines the research questions and the methodology which is applied to the data in the analysis. The results section uses the empirical data from the survey to assess the extent of perceived CE barriers and their relationship to business characteristics and CE technologies. The findings are discussed in Section 5, while Section 6 presents the limitations of the study and the implications for theory, business management and policy.

2. Literature review

Barriers to the implementation of CE practices have been the subject of extensive research in recent decades, with several studies focusing on their identification and classification. Feldman et al. [18] have emphasized that a greater awareness of these barriers is crucial for the transition to a circular economy. At the macro level, Geng & Doberstein [17] identified policy, technology and public participation barriers through an examination of China's sustainable development model. Su et al. [15] expanded on this classification by delineating technical, market, managerial, organizational, financial and economic barriers.

Kirchherr et al. [19] followed up on this discussion by attributing the slow progress in CE adoption within the EU to cultural, regulatory, market and technological barriers.

Various studies have analysed the barriers to CE implementation across different industries and sectors, identifying a range of challenges which are specific to each individual context. Jaeger & Upadhyay [11] examined the context of Norwegian manufacturing and identified seven main barriers, such as lack of technical skills and information on product design and production, quality compromises, high start-up costs and complications in supply chains and business-to-business collaboration. Upadhyay et al. [34] performed a similar study on the English retail industry and identified several CE barriers from the fields of regulation, organizational structure, communication and culture, finance, technology and marketing. García-Quevedo et al. [13] analysed European SMEs across several sectors and revealed the impact of barriers such as the lack of human and financial resources, insufficient expertise and regulatory barriers. Schröter et al. [35] focused on overcoming barriers and implementing recycling concepts in German manufacturing industries and identified technological lock-in and inertia, lack of awareness of material saving potentials because of insufficient information, company strategy, regulatory uncertainties and lack of pressure from the demand side as the key barriers to CE implementation. Moktadir et al. [7] performed a similar study on the leather industry and emphasized technology, legislative shortcomings and a lack of awareness and strategic goals as the main CE barriers. Stumpf et al. [36] identified 13 barriers across 21 sectors, mostly relating to legislation, high costs, technology and a lack of awareness and demand. Rizos & Bryhn [37] identified key categories of barriers to implementing a CE in the EEE sector: policy, financial/economic factors, supply chain, technology, consumer/society and business organization. A study by Sundar et al. [38] focused on U.K. residential e-waste and listed fifteen barriers. As Van Keulen & Kirchherr [39] noted, considerable research has been carried out sector-specific barriers and facilitators, but few studies to date have focused on complex product value chains. In their study, they use case studies from the coffee industry to identify twelve barriers in four categories: values, technology, business cases and government policy.

Some studies (see [20]-[22]) have focused on distinguishing between internal and external barriers to CE, a classification which was first introduced by Chauhan et al. [20] in a study which noted perceived internal barriers within organizations in terms of corporate policies, financial constraints and technological challenges. Hina et al. [21] expanded on this by dividing internal barriers into seven subcategories, including collaboration and product design, while listing possible external barriers such as consumer, legal, economic and supply chain-related factors. Vermunt [22] also highlighted the significance of external forces, such as regulatory and market challenges, in hindering the development of CE practices.

The typology of barriers adopted in different studies is also dependent on the research approach which individual studies applied. Authors typically open their studies with a systematic literature review on the issue of CE principles and the barriers to their implementation (see [7], [10], [15], [21], [40]-[44]). Some studies are built around empirical research; Halse & Jæger [31] used a combination of the two approaches of structured interviews and case studies, while Jaeger & Upadhyay [11] relied on semi-structured interviews. Stumpf et al. [36] applied a mixed methodological approach, employing content and correspondence analysis in a case study of 131 CE projects. Kirchherr et al. [19] used three approaches: desk research, semi-structured interviews and a survey, while Upadhyay et al. [34] relied on content analysis methodology. Other authors conducted survey studies, such as García-Quevedo et al. [13] , who analysed a cross-sectional survey of over 10,000 European SMEs, or Urbinati et al. [45] whose survey-based empirical investigation involved 66 companies from the Italian automotive industry.

Despite growing interest in CE practices, little research to date has explored the relationships between companies' perceptions of barriers to the introduction of CE measures and their specific characteristics, such as industry type, production or product attributes, motivations for CE implementation and additional characteristics such as the year of establishment, nationality, profitability or R&D activities. Existing research has primarily focused on identifying and categorizing CE barriers, including financial, market, organizational, operational and regulatory challenges, rather than addressing how these barriers are perceived relative to company-specific contexts [45], [46]. For example, Urbinati et al. [45] highlighted significant correlations between various barriers such as high product complexity and variability in returned product flows, but they failed to link these findings to specific firm characteristics. Similarly, Mura et al. [28] observed that the adoption of CE practices is negatively correlated with the perception of sustainability as a cost and the lack of regulatory coordination at the EU, national, regional and local levels, but they did not discuss how firm characteristics influence the perception of CE barriers. Schröter et al. [35] also identified a series of CE barriers, but they were primarily focused on a quantitative analysis of recycling-related CE practices in a large dataset of German manufacturing companies and their relation to environmental performance measurement systems, life cycle costing evaluation methods or environmental performance indicators, fields in which significant correlations were identified. García-Quevedo et al. [13] offered a fresh perspective, indicating a potential link between the type of CE practices (namely innovations) and barrier perception, yet this relationship remains underexplored. Their study argues that firms implementing disruptive CE innovations perceive all barriers as significant, but it also notes that companies introducing other CE activities perceive only some barriers.

Within this context, we can see a clear need to address this gap to determine how these barriers are perceived relative to firm-specific contexts. The identification of any correlations can provide a fuller understanding of the nature of these relationships and thereby help tailor policy interventions and support mechanisms to address the unique challenges faced by different types of firms, such as SMEs or large enterprises [28]. Similarly, an in-depth study of CE barrier perceptions can assist companies in overcoming these limitations by aligning their internal capabilities with the specific CE barriers they are likely to encounter in a strategic context, a process which can streamline the transition to more sustainable business models.

Technologies relevant to the CE concept

Among the key sustainable technologies in the manufacturing context are those which are defined as clean process technologies and pollution abatement technologies [47]; these are often divided into three generic categories of energy, water, and material efficiency technologies [48]. Existing literature suggests that each of these generic technologies have their own circular aspect. The first technology examined in the research, energy recovery technology, is a widely accepted method for introducing circularity in manufacturing industries whose importance for different purposes and industries has been noted by several studies, such as [49]-[52]. The second technology, water recycling/reuse technology, has been implemented in a wide range of different industries including iron and steel making [53], the paper industry [54], and the food industry [55]. The crucial role which this technology plays in CE programs has been the subject of considerable research; for example, the assessment model proposed by Vimal et al. [56] mentions water recycling as a criterion of CE measures. The third type of technology are those which improve material efficiency. The use of remanufacturing technology has been studied extensively as the technology represents one of the most applicable post-use strategies in the implementation of circular or closed-loop manufacturing approaches [57]. Remanufacturing technologies conserve materials and energy [58] and are aimed at retaining or regenerating the value of a product throughout its life cycle [59].

3. Data and methodology

3.1 Data

The data used in this study are taken from the European Manufacturing Survey (EMS), a joint European survey project conducted every three years across 17 European countries. The survey is coordinated by Fraunhofer ISI, Germany, and the respondents are manufacturing enterprises (NACE 10 - 33) with more than 20 employees. The EMS consortium uses recommended procedures to collect internationally comparable data, including translation and harmonization processes [60]. EMS explores both technological and non-technological innovation within European industry, with a primary focus on technology diffusion and organizational innovation [61], but including also performance indicators [62]. Each country incorporates some country-specific questions into the standard questionnaire; for example, only two of the participating countries, Slovakia and Slovenia, included questions on CE technologies and barriers in the 2018 period of the EMS project. However, as these two countries act as key suppliers to larger economies, such as Germany and France, this study introduces and depicts the wider value chain, and the data provided in the survey is not limited to the local perspective of the two Central European countries. Our research is based on a total of 241 cases, 127 from Slovenia and 114 from Slovakia (see Table B in Appendix A), collected independently in both countries at the end of 2018 and in the spring of 2019. The representativeness of the national samples was assessed by cross-tabulating the NACE sectors and formulating three size categories for the featured companies.

A 5-point Likert scale was used to obtain data on the perception of CE barriers because, unlike binary formats, Likert-type questions offer more nuanced insights into perceptions [63]. This approach captures a wide range of perceptions in fine-grained detail, allowing for meaningful statistical data analysis without incurring the risk of overwhelming the respondents. Other studies on the CE have obtained valuable results through the use of Likert scales which require respondents to rate barriers and drivers on a 1 to 5 scale (for example, see [64]) or a 1 to 7 scale (for example, see [65]). Based on the wording used in our questionnaire: “Have you experienced any of the following barriers to implementing CE initiatives?” the “extent” type of scale ranging from “not at all” (1) to a “very high degree” (5) was chosen.

It should be noted here that the issue of the complexities involved in defining the CE concept was explicitly integrated into the question in order to avoid misunderstandings on the part of the respondents. Geissdoerfer et al. [66] defined the circular economy as a regenerative system in which resource input and waste, emission and energy leakage are minimized by slowing, closing and narrowing energy and material loops. They argue that this can be achieved through the use of long-term design, maintenance, repair, reuse, remanufacturing and recycling.

3.2 Research approach

The research approach adopted in this study (Figure 1) is divided into several steps. In the first phase, which will be outlined below, barriers to CE implementation identified in the literature review were selected. The data for the research was gathered using the EMS survey described above. The data was collated and tested to ensure that it was representative before being subjected to analysis. A regression model (Figure 2) was used to validate the relationships between the CE barriers and predictors (including production/product characteristics, CE technologies, company attributes and others). All analyses were performed using the R Project for Statistical Computing software.

3.3 Dependent variable

While earlier studied have developed an extensive list of CE barriers has been developed using a variety of different approaches and areas, this paper focuses on seven specific CE barriers as dependent variables (see Table 1): market challenges, economic barriers, a lack of appropriate technologies, legislative barriers, a lack of internal culture, risks of redesigning business models and the difficulties in forecasting benefits. The selection and wording of these barriers were intended to ensure their applicability across all European countries participating in the EMS.

Experts from academia and industry in Italy, the Czech Republic and the Netherlands provided feedback on the proposed CE barriers, while they also had a possibility to suggest additional barriers, but the aim was to refine the list to a limited number of items (ideally fewer than 10) due to the constraints of the questionnaire format. When validating the barrier list, a process which lasted several months, efforts

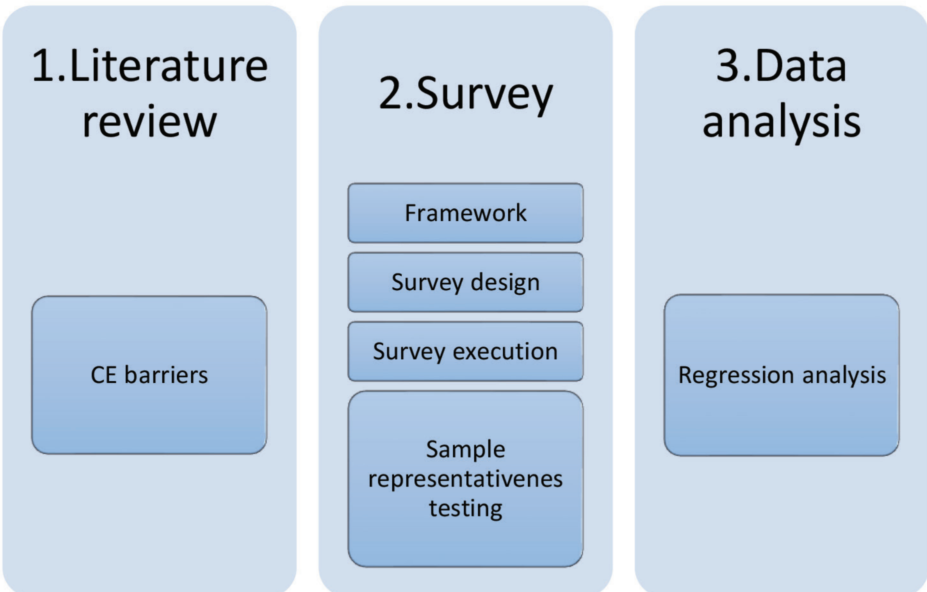

Figure 1. Three stages of the research approach

were made to ensure that the barriers were relevant to manufacturing companies and that the barriers would be comprehensible to production managers or company owners. The result of this phase was the meticulous formulation of the seven barriers outlined in Table 1.

Finally, a pilot survey was conducted in which some companies completed the questionnaire together with the researchers. This served to check their understanding of the questions, especially those relating to CE barriers in Slovakia and Slovenia. In the following subsections, each of these barriers is explained in more detail.

3.4 Independent variables

A series of variables (see Table 2) that delineate the five key aspects which are central to our research were used as independent variables: industry, production/product characteristics, CE technologies employed, motivations for adopting CE measures and other company characteristics, such as size or profitability level.

The variables listed in Table 2 were integrated into the research model based on identified research gaps or their earlier inclusion in other CE barrier studies. If applied on the basis of identified gaps (i.e., no studies found to date), the following variables were introduced: nationality, industry technology intensity, production and product characteristics, scope of R&D activities in the company and profitability level. The inclusion of the nationality variable is justified by the fact that the two countries differ in terms of their business environments, attitudes towards environmental issues and other factors. While Mura et al. [28] had examined the differences between individual industries in terms of CE barriers, their research did not address the technological intensity of the industry which we explore in our study. The characteristic of production, in our specific case the customization of production, requires flexible production processes and more integrated and adaptable supply chains, and the impact of this factor is not wholly clear; while these needs can potentially complicate the implementation of CE principles, it is also possible that companies with more resilient and flexible production programs would be better placed to adopt CE initiatives and comply with regulations. Another characteristic, the size of batch production, may also be associated with perceived barriers, as the production of larger batches could entail less flexible production processes. In addition, differences in the perception of barriers may arise in the context of production to order and production to stock, with product customization, inventory management and production flexibility all potentially exerting an influence.

The complexity of specific products also presents manufacturing companies with unique challenges in terms of end-of-life management. For example, it may be challenging to recover valuable materials from complex products for reuse or to coordinate CE initiatives between suppliers and partners. In addition, complex products may require more advanced technologies for the effective implementation of CE practices, and companies may have to deal with more complicated regulatory frameworks. Another variable is the implementation of R&D activities within the company, an issue which has not been studied in depth in previous studies on CE barriers (see, for example, [67], [68]). The inclusion of the Return on Sales (RoS) variable as a profitability indicator is justified by the predicted relationship between the financial health of the company and economic barriers to CE, an issue which is often identified as one of the more significant barriers to the introduction of CE measures. In addition, profitable companies might be more capable of managing the risks associated with the transition to CE practices. The factor of company size has also appeared in earlier studies on CE barriers (e.g., [24]).

The inclusion of CE motives as independent variables was guided by their relevance, as identified in

Table 1. List of CE barriers included in the study

Barrier (abbreviated)	Barrier (full version from questionnaire)
market challenges	Market challenges in accepting remanufactured or reused products
economic barriers	Economic barriers (e.g. high cost of processes and technologies, etc.)
lack of appropriate technologies	Lack of appropriate and effective technologies
legislative barriers	Legislative barriers
lack of internal culture	Lack of internal culture (or cultural gap) and/or strategic commitment
risk in redesigning business models	Risks involved in redesigning business models for CE
difficulty of forecasting benefits	Difficulties involved in forecasting benefits

Table 2. List of all variables implemented in the study

Groups of variables	Variable	Variable description
INDUSTRY	**Industry technology intensity**	Company is in a high-technology industry Company is in a medium-high-technology industry Company is in a medium-low-technology industry Company is in a low-technology industry
PRODUCTION/ PRODUCT CHARACTERISTICS	**Product customization**	Company develops products according to customer specifications Company develops products in the form of standardized basic programs incorporating customer-specific options Company develops products in the form of standard programs from which the customer can choose options Not applicable for this company
	Production to order	Company commences production upon receipt of the customer's order, i.e., made-to-order
		Company commences final assembly of the product upon receipt of the customer's order
		Company produces to stock
		Not applicable for this company
	Production batch size	Company produces in single unit production
		Company produces in small or medium batches
		Company produces in large batches
	Product complexity	Company produces single products
		Company produces medium complexity products
		Company produces complex products
	PLM/PDM	Company uses the Product-Lifecycle-Management-Systems (PLM) or Product/ Process Data Management
CE TECHNOLOGIES	**Water recycling**	Company uses water recycling/reuse technology
	Energy recuperation	Company uses technologies to regenerate kinetic and process energy
	Remanufacturing	Company uses remanufacturing technology
CE MOTIVES	**CE motive - regulation**	Company is implementing CE initiatives due to legislative requirements
	CE motive - cost saving	Company is implementing CE initiatives to reduce costs due
	CE motive - company value growth	Company is implementing CE initiatives to increase company value
	CE motive- green marketing	Company is implementing CE initiatives to differentiate the company from competitors in terms of their commitment to green policies
ADDITIONAL COMPANY CHARACTERISTICS	**R&D**	Company is currently carrying out R&D or awarding R&D contracts
	Turnover	Company turnover
	Number of employees	Number of employees
	Return on Sales (RoS)	Return on Sales (RoS)
	Year	Year in which the company was established
	Country	Company is from Slovakia (0) or Slovenia (1)

Note: Types of variables: respondents provide numeric values (Turnover, Number of employees, Year); respondents select options on a scale (Return on Sales (RoS)); respondents provide binary "yes/no" answers (other variables).

numerous studies addressing CE barriers and drivers (see [47], [69]-[73]). Some studies (see [47], [69]) have highlighted the positive influence that environmental regulations in the EU can have on the adoption of sustainable process technologies. Similarly, cost savings have also been shown to be associated with the introduction of CE or environmental practices (see [70], [71]). Specifically, Darmandieu et al. [71] confirmed that European SMEs with a higher integration of circularity into their processes have seen a reduction in production costs. The role of "company value growth" as a driver for CE implementation is supported by evidence indicating that the adoption of circular economy principles can significantly enhance financial performance [73], thereby increasing company value. Other research [74] has revealed that green product innovation and green process innovation can be considered as a differentiation strategy which generates a sustainable competitive advantage; green differentiation is also considered to possess the potential to drive the adoption of CE activities. The last variable included in the research model is that of CE technologies, a factor which is of relevance due to their consistency with the fundamentals of CE and the energy and material cycles. It should be clarified, however, that the definition of this variable in this study is more precise (see Table 2) than the more general definition (e.g., "energy efficiency technologies") given in the EMS survey; the experience of many years of surveying manufacturing companies has shown the value of including specific technologies rather than broad categories for the sake of clarity. The final question queried the individual CE technologies which had already been implemented in specific companies, with respondents providing binary "yes/no" answers regarding each of the technologies listed in the survey.

3.5 Regression analysis

A regression model (see Figure 2) was used to validate the relationships between the CE barriers and predictors (including production/product characteristics, CE technologies and others). Since perceptions of barriers were recorded as dependent variables on a Likert scale and represented by a separate ordinal variable for each barrier, an ordered logistic regression model was created for each individual barrier in which the perception of the barrier was the dependent variable y_i, and the production/product characteristics, CE technologies and others were used as independent variables x_i (see Table 2).

The ordered logit model is then defined as:

$$y_i^* = \boldsymbol{x}_i\beta + u_i$$

where y_i^* is an unobservable latent variable. The observed ordinal variable y_i is then based on y_i^* crossing thresholds:

$$y_i = j \text{ if } a_{j-1} < y_i^* \le a_j$$

The probability that observation i will belong to category j is then

$$p_{ij} = p(y_i = j) = p(a_{j-1} < y_i^* \le a_j) = \\ = F(a_j - \boldsymbol{x}_i\beta) - F(a_{j-1} - \boldsymbol{x}_i\beta),$$

where F is a logistic cumulative distribution function.

After a series of standard diagnostic tests, the most appropriate model for each barrier was selected using the Akaike information criterion. The statistically significant coefficients (ordered log-odds) for each model are listed in Table 3. The ordered logit coefficients were interpreted as follows: with a one-unit increase in the independent variable, the level of the dependent variable should be changed by the corresponding regression coefficient in the ordered log-odds scale, with the other variables in the model remaining constant. A positive coefficient indicates that an increase in the predictor is associated with higher log-odds of encountering the specific barrier. A negative coefficient indicates that an increase in the predictor is associated with lower log-odds of encountering the specific barrier. In both cases, the magnitude of the coefficient reflects the strength of this association, while an absence of values indicates that the predictor was not statisti-

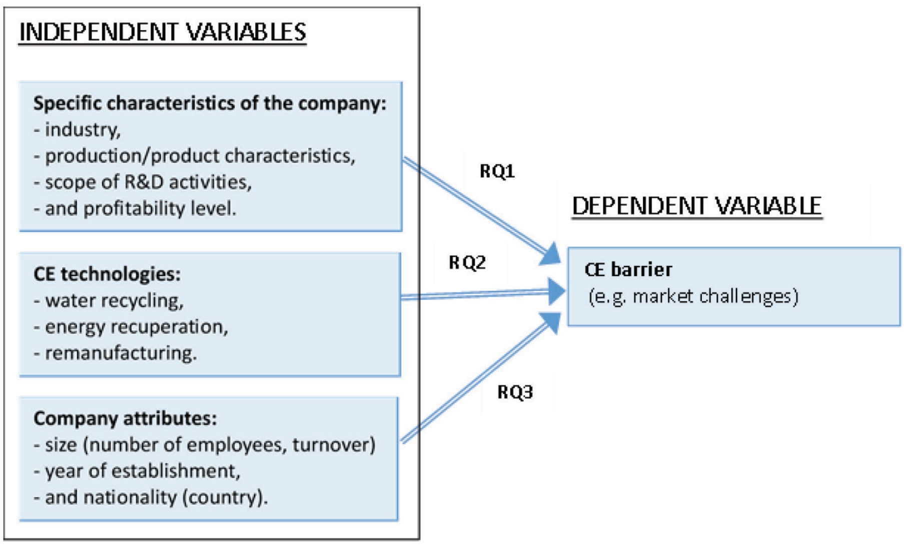

Figure 2. Logistic regression model

Table 3. Ordered logit regression model explaining the perception of barriers. Source: own research

Model / Predictor	Market challenges of reused prod.	Economic barriers	Lack of appropriate technologies	Legislative barriers	Lack of int. culture/ strategic commitment	Risks of redesigning business models	Difficulty in forecasting benefits
Company produces products of medium complexity (in comparison to "complex product")	-0.811	-0.366	-0.399	**-1.013***	-0.117	0.307	0.093
Company develops products according to customer specifications (in comparison to "no product development")	**-1.54****	**-0.846***	-0.002	0.17	-0.414	-0.487	-0.97
Company develops products in the form of standard programs from which customers can choose options (in comparison "no product development")	**-1.849****	-1.346	-0.313	-0.087	-0.416	-1.245	-0.6
Company produces in single unit production (in comparison to "large batch")	0.774	0.638	0.104	0.479	**1.142***	0.229	0.778
Company commences final assembly upon receipt of the customer's order (i.e., assembly-to-order in comparison with "production to stock")	-1.144	**-1.307***	-1.149	-1.703	-1.464	-0.078	-0.762
Company is from Slovenia (in comparison with Slovakia)	**0.821***	-0.538	-0.174	**-1.099****	0.375	0.889	-0.019
Turnover of the company [mil. EUR]	0	**0.004***	-0.001	-0.002	0	-0.007	0.001
Number of employees of the company	0	0	0.002	0	**0.001***	0.001	0
Return on Sales (RoS) of the company	**-0.375***	**-0.34***	-0.185	-0.198	-0.187	**-0.393***	**-0.401****
Company is implementing CE initiatives on the grounds of cost-cutting	-0.135	0.546	**0.838***	0.15	0.063	0.266	0.185
Company is implementing CE initiatives on the grounds of green marketing	0.618	-0.036	0.178	0.091	0.319	**1.083***	0.193
Company uses the Product-Lifecycle-Management-Systems (PLM) or Product/Process Data Management	-0.711	-1.055	**-1.278****	-0.663	-0.835	0.138	**-1.068***
Company uses water recycling/ reuse technology	0.867	-0.648	0.15	-0.325	-0.209	-0.745	**-0.835***
Company uses technology to regenerate kinetic and process energy	**0.967***	0.449	0.274	**0.955***	0.168	0.687	0.069
Company uses remanufacturing technology	**0.741***	0.833	**0.77****	**1.175****	**1.294****	0.397	**0.743***

Note: Columns represent independently executed ordered logit regression models of specific CE barriers. * denotes a 0.05, ** a 0.01 and *** a 0.001 level of significance.

cally significant for the corresponding barrier in the ordered logit regression model. All calculations were carried out using the R Project for Statistical Computing software program.

4. Results

Table 3 offers a more detailed statistical analysis of the perception of the barriers in companies, showing the factors (or predictors) which are associated with various barriers to CE initiatives in manufacturing companies in Slovakia and Slovenia. Each row represents a specific predictor (i.e., independent variable), and each column displays the ordered logit model for a specific barrier (i.e., dependent variable). Only significant predictors from the total series of the studied variables (see Table 2 and Appendix A) are displayed. Each coefficient value represents the log-odds of the corresponding barrier being influenced by the predictor. Positive coefficients indicate a higher likelihood of encountering a specific barrier with an increase in the predictor, while negative coefficients indicate a lower likelihood.

The following is an example of how the statistics were interpreted during the analysis: the coefficient for "Economic barriers" shown in the second row is -0.846, suggesting that companies developing products according to customer specifications are less likely to encounter economic barriers to the introduction of CE measures; in contrast, the coefficient in the fourth row for "Lack of internal culture/strategic commitment" is 1.142, suggesting that companies using single-unit production processes are more likely to encounter barriers related to internal culture and strategic commitment.

A more detailed analysis can help us to understand how different factors and technologies influence the perception of barriers to circular economy initiatives in manufacturing companies in Slovakia and Slovenia, providing valuable insights for strategic planning and policy formulation, and this will be explored the following section of the paper.

4.1 Results from the perspective of specific CE barriers

A more comprehensive analysis of the data can provide information on each individual barrier to CE initiatives separately, taking into account all of the various variables/predictors, such as turnover, number of employees, nationality, RoS and existing CE technologies.

1. Market Challenges of Reused Products

The coefficients listed in the second column (see Table 3) indicate that companies developing products according to customer specifications or via a standardized program from which the customer can customise their options and companies with higher RoS are less likely to face market challenges for reused products. Conversely, Slovenian companies and companies that use energy recuperation or remanufacturing technologies were found to be more likely to encounter this barrier.

2. Economic Barriers

The results presented in the third column (see Table 3) indicate that companies developing products according to customer specifications, using assembly-to-order manufacturing, or have higher RoS are less likely to face economic barriers. On the other hand, larger companies (measured by turnover) are more likely to face this barrier.

3. Lack of Appropriate Technologies

Companies that use PLM (or PDA) systems were found to be less likely to experience a lack of suitable technological means. In contrast, however, companies that implemented CE initiatives for cost-cutting reasons and those that already use remanufacturing technologies were more likely to encounter this barrier.

4. Legislative Barriers

The results for this factor indicate that companies producing products of medium complexity (in comparison to "simple products" or "complex products") or those from Slovenia were less likely to encounter legislative barriers. The opposite was the case for companies that already use energy regeneration or remanufacturing technologies.

5. Lack of Internal Culture/Strategic Commitment

Three significant predictors were identified for this barrier: companies that produce in single-unit production (in comparison to "small or medium batch" or "large batch"), larger companies (measured by the number of employees), or companies that use remanufacturing technologies were all seen as more likely to encounter this barrier.

6. Risks of Redesigning Business Models

Our results indicate that companies with higher RoS are less likely to face this particular barrier, while companies that consider green marketing or differentiation from competitors as the reason for implementing CE initiatives are more likely to perceive this as a limiting factor.

7. Difficulties in Forecasting Benefits

Our results suggest that companies that use PLM (or PDA) systems, water recycling technologies or have higher RoS are less likely to encounter this issue, while companies that use remanufacturing technologies are more likely to face this barrier.

4.2 Results from the perspective of specific predictors

This section focuses on individual or multiple predictors (or independent variables), firstly in terms of the effect of companies' production/product characteristics, secondly in the context of RoS and additional company characteristics, and lastly through an analysis of the effect of the use of CE technologies.

The results presented in the first five rows of Table 3 listing company production and product characteristics indicate that companies developing products according to customer specifications or via a standardized program from which the customer can choose options, those producing products of medium complexity or using made-to-order manufacturing are less likely to encounter some CE barriers. Conversely, companies that operate single-unit production methods are more likely to perceive a lack of internal culture/strategic commitment as a barrier.

Considering the effect of additional company characteristics on the perception of CE barriers, our results suggest that larger companies are more likely to perceive the impact of economic factors and a lack of internal culture/strategic commitment as potential barriers. Similarly, the nationality of companies is also deemed a relevant predictor in the case of the market challenges of reused products and legislative barriers.

One particularly interesting and coherent finding is related to the RoS variable. As is shown in Table 3, companies with higher RoS are less likely to face four (out of seven) barriers, including economic factors and the risks involved in redesigning business models.

Our regression model also shows that the prediction of CE barriers perception by CE motives is largely anecdotal in nature.

Finally, the results in the lower part of Table 4 indicate that companies that have already implemented CE technologies (especially remanufacturing technology) are predominantly more likely to perceive a variety of barriers. Conversely, companies that use PLM (or PDA) systems are less likely to consider the lack of appropriate technologies and difficulties in forecasting benefits as potential barriers.

5. Discussion

The core findings of our study represent a considerable contribution to ongoing empirical and theoretical discussions concerning the perception of barriers to CE implementation, with three aspects proving particularly rewarding. Firstly, specific company characteristics as size, nationality (Slovenia vs. Slovakia), profitability level, product/production characteristics, motivations for introducing CE measures and existing implementations of CE technologies have been shown to play a role in influencing perceptions of CE barriers. Secondly, companies with higher profitability levels (as measured by RoS) show a tendency to view the majority of CE barriers as less significant in comparison with companies with lower profitability levels. And thirdly, companies with prior experience of implementing CE technologies are more likely to perceive CE barriers to a greater extent in comparison with companies without this previous experience; a similar finding was identified in the context of barriers to innovations. Each of these findings will now be discussed in more detail.

Our finding that larger companies are more likely to perceive potential barriers to the implementation of CE measures is in agreement with the conclusions of a study by Trianni et al. [24] which also found that perceived barriers to energy efficiency are more pronounced in medium-sized enterprises in comparison to smaller firms. The Fusion Observatory Report which focused on SMEs found that most of the companies which it surveyed in its research had either never heard of the concept of the circular economy or were unaware of its meaning [41]. This may suggest that SMEs have a limited ability to perceive barriers, according to information shortage in comparison to larger companies.

As far as we are aware, the relationship between perceptions of CE barriers and the country in which companies operate has not been explicitly covered in previous studies. A study [75] comparing CE barriers in EU and Russia found that the prioritization of barriers was significant in determining differences; Russian companies are more sensitive to imperfect government regulation and the lack of cooperation with cross-sectional stakeholders. Our finding that the location of a company is significant in predicting two of seven researched barriers (specifically the fact that in Slovenia "Market challenges of reused products" is more likely to be perceived and "Legislative barriers" less likely to be perceived) supports the suggestion that different countries have varying perceptions of CE barriers.

Our results suggest that profitability levels (measured in terms of RoS) had a significant influence on perceptions of four of the seven barriers, including that of "economic barriers"); unsurprisingly, companies with higher RoS perceived this barrier to a lesser extent than other companies. Given these findings, we can clearly conclude that a company's financial performance and success correspond to the perceived significance of CE barriers.

The findings related to the characteristics of production and products (see the first five rows in Table 3) are somewhat ambiguous and difficult to parse. However, it is possible to suggest that the "Company develops products according to customer specifications (in comparison to other options:)" predictor indicates that these companies are less likely to perceive "market challenges of reused products" as a barrier because their customer-centric design approach and established customer relationships have the potential to promote reused materials and mitigate scepticism over their use.

Studies have identified cost saving measures as a motivating factor for CE implementation in European SMEs; for example, the desire to reduce material costs [76] or production costs [71]. However, little attention has been paid to the interaction between cost-saving motivations and the perception of CE barriers. Our results did not identify any significant correlation between these two factors, and the single anecdotal connection related in Table 3 is also ambiguous. Nonetheless, the presence of the "cost-saving" CE motive suggests a higher likelihood for the perception of the "Lack of appropriate technologies" barrier, although it remains open to speculation whether companies that are cost sensitive might consider the accessibility of CE technologies through a cost or affordability perspective.

Regarding other CE motives, our regression model identified only one additional anecdotal relationship, namely the fact that the "Green marketing / differentiation" CE motive indicates a higher likelihood of the perception of the "Risks of redesigning business model" CE barrier. This relationship seems plausible if we assume that the implementation of green marketing/differentiation requires substantial changes to be made to the business model, requiring initial investment and possibly incurring process redesign risks.

The research also touches upon the debate over digital and green measures. Our findings suggest that companies using PLM or PDA systems are less likely to perceive a lack of appropriate technologies and difficulties in forecasting benefits as barriers to CE adoption. This conclusion is in alignment with the findings reported by Ghobakhloo [77] which highlight how Industry 4.0 technologies enhance interfunctional collaboration, improve knowledge management and strengthen organizational capabilities for sustainable innovation. As a result, it can be suggested that Industry 4.0 subsequently enhances the innovative capacities of green processes.

The new findings offered by our research are also apparent in the results delineating the relationship between barriers and technology. Companies that have prior experience with the adoption of CE technologies were found to be more likely to perceive barriers to CE implementation (see last two rows in Table 3). This result echoes the findings of Mura et al. [28] which suggest that companies which have already implemented CE practices perceive the "lack of regulatory coherence" as an extremely salient obstacle. Interestingly, this somewhat counterintuitive result was also observed in other studies that focused on innovation barriers in companies, such as research by D'Este et al. [78], Demirbas [79] and Santiago et al. [80], which found that companies that engage heavily in innovative activities are more likely to perceive barriers as more serious than companies that are less innovative. Iammarino et al. [81] explain this surprising result in the empirical literature by suggesting that innovators are more likely to have experienced barriers in practice and are therefore more likely to consider the barriers to be significant. A more detailed explanation is provided by Galia & Legros [82], who point out that specific problems may only be recognized when companies are confronted with them. De Fuentes et al. [83] add that companies' perceptions of barriers to innovation increase in line with their growing commitment to innovation because complications can often mount as innovation processes become more complex. Finally, Iammarino et al. [81] warned of a possible endogeneity issue due to a reverse causality between the perception of barriers and a company's innovation activities, suggesting that further research is needed to clarify this issue. Considering the results presented in the field of barriers to innovation, we assume that the explanation of this phenomenon in the case of CE barriers is also related to a company's prior experience with CE initiatives. In other words, respondents are more likely to assess barriers more highly on a Likert scale because they are more aware of potential issues based on their existing knowledge about the adoption of CE technologies.

6. Conclusions

In general, our results show how different factors and technologies influence the perception of barriers to the implementation of CE initiatives in manufacturing companies. The relationships between the perceptions of some CE barriers and factors (or characteristics) such as product/production characteristics and profitability level which we have identified in our analysis have only partially answered the first research question, because other assumed factors such as the specific industry type and the scope of R&D activities do not seem to be related. Our results also suggest a new finding concerning the relationship between prior experience with CE technology adoption and perceptions of CE barriers, with companies that currently use or have used CE technologies in the past showing a greater likelihood of perceiving potential barriers to CE implementation than was found in other companies, a conclusion that follows from the second research question. While it should be noted that a similar phenomenon has been identified in studies on barriers to innovation, this is the first time that a clear link has been drawn between this issue and perceptions of barriers to CE implementation. In terms of the third research question which focused on the relationship between perceptions of CE barriers and company attributes (i.e., size, year of establishment and nationality), the results suggest that only nationality (country) seems to be related to the perceptions.

6.1 Theoretical Implications

The findings of this study represent a significant contribution to the existing body of knowledge on the CE, particularly in the context of Central European manufacturing.

The study's exploration of the ways in which specific company characteristics (e.g., industry, production/product, size, profitability) influence perceptions of CE barriers adds a layer of granularity to existing theories. The role of profitability, in which companies with higher RoS perceive barriers as being less significant, offers empirical support for the validity of resource-based and capability theories which posit that more profitable firms possess greater resources and capabilities to overcome operational challenges. This insight calls for an expansion of current CE theories to account for variations in perceptions based on the financial status of individual companies.

Furthermore, the observed relationship between prior experience of CE implementation and a heightened awareness of CE barriers also has important theoretical implications. We believe there are two key reasons why this finding is both relevant and significant. Firstly, no previous study has identified this relationship to the best of our knowledge. Secondly, its significance extends beyond the discourse relating to CE, as it supports the broader validity of a similar phenomenon observed in studies on barriers to innovation in general (e.g., [78]-[81]). Studies on innovation suggest that engagement in innovative activity increases firms' awareness of the associated difficulties [81]. This implies that CE theories should integrate dynamic capability perspectives to deepen our understanding of the field. As with discussions of innovation, we should also consider the possibility of an endogeneity issue, a reverse causality [81] or a bidirectional relationship; companies may perceive more barriers as they engage in CE activities, but these perceptions could also influence their willingness or approach to CE adoption. This underscores the need for further research to disentangle these dynamics.

6.2 Empirical Implications

From an empirical standpoint, this study provides actionable insights for policymakers, business leaders and CE advocates in Central Europe and beyond. The analysis highlights the impact of company-specific characteristics, such as size and profitability, on barrier perception, suggesting that CE strategies should be differentiated according to company profile. For example, larger or more profitable firms may require less external support compared to smaller firms that may need more targeted assistance, such as grants or knowledge-sharing networks, to lower their barrier perceptions. Additionally, the finding that Slovenian and Slovak firms perceive barriers differently points to the importance of national contexts in shaping business attitudes toward CE. Policymakers might need to collaborate with stakeholders to design region-specific programs that resonate with the specific characteristics of their industries and regulatory environments. Finally, the greater perception of barriers among companies with prior experience of CE implementation suggests that, despite their experience, they might be less active in further CE adoption.

6.3 Practical implications

Our results offer valuable insights also for companies. Manufacturing companies that encounter barriers in the implementation of CE principles can overcome these issues through approaches that reflect the perceptions and characteristics of the companies identified in our research. For example, it appears that managers and business owners may reduce their exposure to significant economic barriers - often cited in the literature (e.g. [11], [24], [47]) as among the most common - by adopting strategies such as developing products according to customer specifications or employing assembly-to-order manufacturing. Another example is that the use of Product Lifecycle Management systems may help reduce exposure to barriers related to a lack of appropriate technologies and difficulties in forecasting benefits. In addition, the results provide a valuable analysis of the concerns that might influence managers of companies when deciding to adopt a particular CE technology or when these technologies are already in place. Our findings can help managers to assess different potential CE barriers in different organizational and technological contexts simultaneously.

It is also important, however, to remain aware of the possible limitations of this study. One issue may lie in the relatively small number of identified barriers, an inevitable consequence of the limited scope of the study. A further limitation relates to the geographical scope of the survey. Although fifteen countries participated in the EMS 2018 survey, Slovakia and Slovenia were the only countries that incorporated questions on the perception of CE barriers in their national questionnaires. In addition, there is no focus on the qualitative approaches for exploring regional or contextual differences. A third limitation concerns the continuing lack of awareness about the concept of CE among the business community and the general public. In order to ensure that respondents to the EMS survey have a better understanding of the concept, we have provided a brief definition of CE in the questionnaire itself.

Overall, these findings should contribute to the formulation of more effective CE policies and practices that take into account firm-specific and contextual factors, thereby supporting a more holistic approach to CE implementation in the manufacturing sector.

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Appendix A

Table A: Ordered logit regression model of "Market challenges of reused products" CE barrier

Predictor	Coefficient (ordered log-odd)
Company produces **simple products** (in comparison to "complex product")	-0.409
Company produces **products of medium complexity** (in comparison to "complex product")	-0,811
Company **develops products according to customer specifications** (in comparison to "no product development")	**-1,54****
Company **develops products in the form of basic program incorporating customer-specific options** (in comparison to "no product development")	-1.098
Company **develops products in the form of standard programs from which customers can choose options** (in comparison "no product development")	**-1,849****
Company produces in **single unit production** (in comparison to "large batch")	0,774
Company produces in **small or medium batch production** (in comparison to "large batch")	0,331
Company commences **production upon receipt of the customer's order**, i.e. made-to-order (in comparison to "production to stock")	-0,514
Company commences **final assembly upon receipt of the customer's order**, i.e. assembly-to-order (in comparison to "production to stock")	-1.144
Company is from **Slovenia (in comparison to Slovakia)**	**0,821***
Turnover of the company [mil. EUR]	0
Number of employees of the company	0
Return on Sales (RoS) of the company	**-0,375***
Company is implementing CE initiatives on the grounds of **regulation compliance**	-0.466
Company is implementing CE initiatives on the grounds of **cost-cutting**	-0,135
Company is implementing CE initiatives on the grounds of **company value growth**	0.458
Company is implementing CE initiatives on the grounds of **green marketing**	0,618
Company uses the **Product-Lifecycle-Management-Systems** (PLM) or Product/Process Data Management	-0,711
Company **uses water recycling/reuse technology**	0,867
Company **uses technology to regenerate kinetic and process energy**	**0,967***
Company **uses remanufacturing technology**	**0,741***

Note: Second column represents ordered logit regression models of "Market challenges of reused products" CE barrier. * denotes a 0.05, ** a 0.01 and *** a 0.001 level of significance.

Table B: Descriptive statistics

Variable description	Slovakia (n=114)	Slovenia (n=127)	Notes
Market challenges in accepting remanufactured or reused products	1.8	2.0	Mean of scale(1-5)*
Economic barriers (e.g. high cost of processes and technologies, etc.)	3.0	2.9	Mean of scale(1-5)*
Lack of appropriate and effective technologies	2.3	2.7	Mean of scale(1-5)*
Legislative barriers	2.5	2.3	Mean of scale(1-5)*
Lack of internal culture (or cultural gap) and/or strategic commitment	1.9	2.3	Mean of scale(1-5)*
Risks involved in redesigning business models for CE	2.2	2.5	Mean of scale(1-5)*
Difficulties involved in forecasting benefits	2.6	2.5	Mean of scale(1-5)*
Company is in a high-technology industry	4.4	3.9	%
Company is in a medium-high-technology industry	41.2	33.9	%
Company is in a medium-low-technology industry	28.9	52.0	%
Company is in a low-technology industry	25.4	10.2	%
Company develops products according to customer specifications	48.2	54.9	% yes
Company develops products in the form of standardized basic programs incorporating customer-specific options	23.7	27.9	% yes
Company develops products in the form of standard programs from which the customer can choose options	14.0	12.3	% yes
Not applicable for this company	15.8	4.9	% yes
Company commences production upon receipt of the customer's order, i.e., made-to-order	78.9	78.0	% yes
Company commences final assembly of the product upon receipt of the customer's order	8.8	9.4	% yes
Company produces to stock	10.5	11.8	% yes
Not applicable for this company	0.0	0.8	% yes
Company produces in single unit production	23.7	20.8	% yes
Company produces in small or medium batches	43.0	44.0	% yes
Company produces in large batches	36.0	35.2	% yes
Company produces single products	24.6	15.2	% yes
Company produces medium complexity products	51.8	56.0	% yes
Company produces complex products	22.8	28.8	% yes
Company uses water recycling/reuse technology	14.3	38.5	% yes
Company uses technologies to regenerate kinetic and process energy	22.7	34.2	% yes
Company uses remanufacturing technology	15.2	37.0	% yes
Company is implementing CE initiatives due to legislative requirements	20.2	36.8	% yes
Company is implementing CE initiatives to reduce costs due	54.4	74.6	% yes
Company is implementing CE initiatives to increase company value	20.2	42.1	% yes
Company is implementing CE initiatives to differentiate the company from competitors in terms of their commitment to green policies	23.7	21.1	% yes
Company uses the Product-Lifecycle-Management-Systems (PLM) or Product/Process Data Management	18.5	20.8	% yes
Company is currently carrying out R&D or awarding R&D contracts	20.2	59.3	% yes
Company turnover	36.2	47.6	Mean (mil EUR)
Number of employees	178.2	259.4	Mean
Return on Sales (RoS)	3.0	3.3	Mean of scale(1-5)**
Year in which the company was established	1993.2	1986.7	Mean
Company is from Slovakia (0) or Slovenia (1)	47.3	52.7	%

* Scale ranging from "not at all" (1) to a "very high degree" (5)
** Scale of RoS ranging: negative (1), 0-2% (2), 2-5% (3), 5-10% (4) , >10% (5)