



Research article

Clearing the fog: How circular economy transition can be measured at the company level

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ABSTRACT

How far has the transition process to a circular economy progressed? How can this transition process be promoted? So far, the indicators used to analyse such questions have mostly been based on aggregate recycling rates or waste volumes. However, circular economy is much more than that. This paper develops a concept for empirically measuring the transition process along a company's value chain. The concept distinguishes 27 business activities that are relevant for the circular economy and thus enables detailed statements about the transition to the circular economy along the entire value chain and the three dimensions of the circular economy, i.e. efficiency, closing the resource loop and extending product life. Based on this concept, a representative survey of 8,000 Swiss companies was conducted. The data allow – for the first time and for a representative sample – the analysis of the determinants of the transition process to a circular economy using econometric estimations. The results suggest that the transition process has just started; most companies involved in circular economy activities focus on efficiency enhancing measures rather than on extending the life of products/services or closing the loop. In addition, the results show that circular economy *pioneers* are characterized by a willingness to invest a significant amount of available capital in the breadth of circular activities, have greater financial flexibility, and in some cases face greater non-price competition. Ultimately, the results suggest that the transition to a circular economy can only be successful if the necessary framework conditions are set in such a way that it is profitable for the company to significantly increase the degree of circularity.

1. Introduction

To date, most companies have operated in linear business models, in which natural resources serve primarily as production inputs for mass-produced goods that are purchased and generally discarded after single use (Esposito et al., 2017). In a circular economy (CE), resources do not end up in waste at the end of the cycle, but are used for as long as possible. The building blocks of a CE are innovative adaptations of products, services, and processes throughout the corporate value chain to (a) increase resource efficiency by using fewer resources per product (Bocken et al., 2016), (b) slow resource loops by extending product life, and (c) close resource loops through recycling and re-use (Stahel, 1994, 1997; Braungart et al., 2008; McDonough and Braungart, 2010). While the relevance of such a CE transition is undisputed in the literature, it is unclear whether the transition has already begun. Indicators measuring CE are mostly based on aggregate recycling rates or waste volumes. Specific CE activities such as circular redesign of products or re-use of existing materials are not directly captured by

these measures, making it difficult to determine the current status of the CE transition. If climate targets are to be met, there is not much time left for adaptation (EU, 2020b). Therefore, it is important to know where the transition currently stands.

This paper proposes a new empirical approach to monitor CE activities across different industries and size classes. Such monitoring is critical for developing and evaluating policy and business actions in this area. Only if CE can be mapped precisely with indicators is it possible to track developments and check whether policy measures are having the desired effect. Furthermore, such data is also important for companies and industry associations to assess where they stand in this transformation process and how they compare to others. In addition, this concept was used to collect representative data on the current status of the transition CE at the company level for Switzerland. This data is used to analyse the characteristics of the companies in CE — and in particular the *pioneers* in this area. The results make it possible for the

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Nomenclature

| | |
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| C2C | Cradle to Cradle |
| CE | Circular Economy |
| CEO | Chief Executive Officer |
| CFO | Chief Financial Officer |
| ICT | Information and Communication Technology |
| R&D | Research and Development |

first time to describe, in a representative manner for an entire country, where the transition to a CE currently stands, in which areas progress is limited, and where political action may be needed to accelerate the transition.

The data are analysed using descriptive statistics and econometric regression analysis. Given the nature of the data, fractional logit and multinomial logit regression analysis are proposed to identify the main determinants that distinguish (highly) active firms from those that have not yet integrated any or hardly any CE activities along their supply chain. The results suggest that *pioneers* are, on average, larger companies that face non-price competition,¹ successfully launch new products, and have the resources to invest in CE activities. While financial resources and market orientation are mainly decisive for increasing the number of CE activities, innovation capability and the degree of digitization seem to be important for the integration of CE measures in general.

2. Conceptual background

Several recently published review articles provide an overview of the literature on theoretical approaches, strategies, and implementation cases of CE (Lieder and Rashid, 2016; Kalmykova et al., 2018; Sarja et al., 2021). They provide transparency on the current understanding of the CE concept (Kirchherr et al., 2017), the similarities and differences with other sustainability concepts (Geissdoerfer et al., 2017; Homrich et al., 2018), and the possible limitations of the CE concept (Korhonen et al., 2018). In addition, several studies have developed instruments for implementing the CE concept (Kalmykova et al., 2018) and identified strategies to lead companies to CE practices (Bocken et al., 2016).

While the theoretical concept of CE has been widely explored, empirical studies related to CE activities are comparatively scarce (Elia et al., 2017). Moreover, there is a lack of empirical concepts to measure the impact of CE practices, as well as established measures and indicators for this purpose (Moraga et al., 2019). For example, based on various macro-level outcomes such as municipal waste, secondary raw materials, innovation, or food waste, the EU has developed several indicators to track progress towards CE over time (see Moraga et al., 2019, for an overview of existing CE indicators in different countries). In addition, several studies have attempted to identify the economic and/or environmental impacts of CE, again mostly at the macro level (for an overview see Rizos et al., 2017).

The information available to date on material flow analyses, recycling rates and waste volumes does not adequately explain how CE works at the company-level. CE is not just about recycling and waste. These activities are taken only when all other options have been exhausted. To understand the mechanisms within the CE system, it is

¹ Competitive situation in which the following dimensions are important for competitiveness: product differentiation (“customization”), product quality, (frequent) introduction of new products, technical lead, flexibility in meeting customer requirements, services.

necessary to go deeper and examine the processes that lead to these recycling rates and waste volumes. To a large extent, these processes take place within companies. They determine what inputs are used for production, how products are designed, and how production occurs. Usually, the potentials on the micro level can hardly be identified as an effect of CE activities on the macro level, because it is difficult to separate the effect from regular, e.g. structural, changes within an industry (Meyer et al., 2014; Horbach et al., 2015). Moreover, the quantitative models used are sometimes based on simplifications and assumptions that could be questioned (Huhtala et al., 2015).

To better accompany the transition process from a linear economy to a CE, indicators are needed that specifically target CE activities in companies. The lack of robust empirical data at the company level can lead to misconceptions and misleading implications for policymakers and business leaders (as illustrated, e.g., by Agrawal et al., 2012). Given these concerns, there is a fundamental need for empirically based research (Atasu and Van Wassenhove, 2010; Agrawal et al., 2012; Souza, 2013). For sound policy and business decisions, it is important to have more detailed and comprehensive knowledge about the development of a CE at the intermediate company level. Hence, the analysis of CE should aim to move from the macro to the micro level (Elia et al., 2017).

3. Developing a standardized empirical concept

3.1. The starting point: Some prominent examples

There are several examples from different industries that show how the building blocks of a CE can be implemented in practice. A prominent example illustrating the idea of circular product design is *Patagonia*, a manufacturer of outdoor clothing and gear.² The use of recycled and environmentally friendly raw materials, multifunctionality, durability, and reparability are key aspects for the company. *Patagonia* internally evaluates all of its products on these dimensions, which has led to these product characteristics being deeply embedded in the company’s philosophy and in several departments. Efforts are not limited to design, but extend to the entire value chain. Production increasingly runs on renewable energy. To ensure high standards of reparability, the company has established the largest outdoor gear repair centre in the U.S. and operates mobile repair shops that travel to major outdoor sporting events and repair garments free of charge. In addition, the company has created special incentives to get textiles back after customers have used them to re-use them in its production process. In 2019, the percentage of recycled materials in clothing was 31%.

Caterpillar, a global manufacturer of construction and mining equipment, focuses primarily on closing the loop by producing a product that is designed to be remanufactured multiple times, rather than increasing efficiency by using less material.³ By establishing remanufacturing programs and offering like-new products at a fraction of the cost of buying new equipment, they extend the life of their equipment and offer their customers a new machine warranty. Today, remanufacturing is the central pillar of *Caterpillar*’s CE strategy. New equipment is designed to be easily remanufactured, and no distinction is made between new and remanufactured equipment when they are sold. *Caterpillar* recorded 91% eligible returns of end-of-life equipment in 2019, representing a total value of £153 million (approximately €190 million) in materials. Dedicated facilities have been created for this purpose. As soon as a machine arrives, it is disassembled down to the smallest part. Each part

² All information in this section is derived from reports (e.g., benefit corporation report) available on *Patagonia*’s website (Link), accessed June 2022.

³ All information in this section is derived from reports (e.g., sustainability report) available on *Caterpillar*’s website (Link), accessed June 2022.

is cleaned and tested against strict technical specifications to determine if it can be effectively reused. If so, they are restored in innovative processes using the same technical procedure as for new equipment.

Tarkett is a global flooring and sports surfaces company with a strategic vision of sustainable development.⁴ Building on Interface's pioneering role in this industry (see Stahel, 2010), the company integrates CE activities along its entire value chain. In procurement, they selectively use waste products from other industries. For example, they use calcium carbonate, a waste product from Dutch drinking water plants, as a raw material for the production of carpet backing. Together with KLM, they developed a new type of carpet for aeroplanes made from wool scraps combined with snippets of discarded uniforms worn by stewards and stewardesses. In addition, the focus is on healthy fabrics. 98% of the raw materials – more than 3000 ingredients – are evaluated by independent third parties for their impact on the planet and human health according to Cradle-to-Cradle (C2C) criteria. In addition, the carpets are modular, consisting of individual carpet tiles that can be easily replaced as needed. Great attention is also paid to the recyclability and reusability of the products. The bitumen-free and specially designed backing of some of their products can be 100% recycled in their own production cycle. For post-use, a comprehensive take-back program has been implemented to collect installation waste and used carpet tiles and recover the nylon for depolymerization, repolymerization and re-use in production. Once returned, the carpets are processed in special recycling facilities that separate the yarn and other fibres from the backing. With the introduction of a carpet leasing system, Tarkett has also sought to increasingly develop its floors into a service, where the floors remain the property of Tarkett, but customers have the opportunity to use the products without having to worry about maintenance and repairs.

3.2. Developing an empirical concept

Mapping CE activities – as implemented by the three companies presented – into a standardized concept is challenging. It is not possible to refer directly to the concept of CE (e.g., percentage of employees in CE) because in practice there is no common understanding of what exactly this concept means for a particular company. This paper presents for the first time a concept that allows data on CE activities to be collected in a standardized way using a written survey. Rather than referring directly to the concept CE, a company's circularity is measured indirectly by identifying activities that ultimately make a company more circular.

Identifying all business activities that can be attributed to CE is complex because production-related opportunities for action vary by sector and company. However, in order to compare activities between companies, a consistent approach is needed. In order to be able to collect representative data, it is also important that the concept is easy to understand. The written survey should not be too time-consuming to respond to minimize the risk of a low response rate. Complex calculations, as are common in material flow analyses, can hardly be implemented in this way.

Based on existing literature and a structured analysis of implemented activities of well-known companies on CE – such as Patagonia, Caterpillar or Tarkett – activities along the entire value chain were identified that a company can implement to become more circular (see Fig. 1). All of these activities were then assigned to a specific stage of the value chain. Using the value chain analogy was advantageous because companies are generally familiar with this concept and can therefore quickly navigate the survey. In addition, the activities were grouped together to reduce complexity and minimize response time without losing completeness.

Based on this prototype empirical concept, two rounds of pretesting were conducted. In the first round, specific feedback was obtained from 10 experts in the field of CE and eco-innovation; 3 of them had a background in academic research, 3 in sustainability certification, 2 in sustainability consulting, and 2 worked at the Federal Office for the Environment. The goal of this round was to verify if the concept covers all relevant aspects of CE or what is still missing. After reviewing the results of this first round, the concept was adapted. In the second round, the adapted concept was then tested for usability and comprehensibility using a qualitative case study design (including semi-structured interviews and a document analysis) at 10 companies from different industries and sizes. Specifically, one company from each of the following industries was considered: logistics, banking, insurance, textiles/clothing, construction, printing, electronic products, medical technology, and information technology. In order to make the logic of the structure more comprehensible and to reduce the time required to answer the questions, the activities were subsequently restructured slightly, the questions were made more precise, and in some cases they were combined.

Ultimately, the current concept identifies 27 different CE activities (see Table A.1). Activities for all three dimensions of the circular economy were considered, i.e. activities that increase *efficiency* (red dots in Table A.1), contribute to closing resource *loops* (green dots) and also those that slow down resource loops by extending product *life* (blue dots).

4. Data

Based on this concept, a representative survey was conducted in 2020.⁵ This survey asked for which of these 27 activities companies had achieved measurable change between 2017 and 2019. As is common in empirical mapping of diffusion and development of new technologies (e.g., innovation activities or digital technologies), the focus of the analysis was on current activities. Accordingly, the focus of the current survey was on mapping the transition process rather than the level of transition. In addition to information on the measures implemented, information was also collected on the degree of integration into the business model, on the investments made and on the revenues generated, allowing a largely differentiated description of the company's activities in the area of CE.

To draw meaningful conclusions from the data, it is important that the underlying sample correctly reflects the existing industry structure. Only in this way is it possible to make representative statements and derive well-founded recommendations. It was decided to conduct the survey in Switzerland. There are two reasons for this. First, with the KOF Enterprise Panel,⁶ a representative company panel for Switzerland that correctly reflects the business structure of companies with more than five employees. Second, Switzerland is a particularly exciting case for the CE. Besides human capital and water, Switzerland has hardly any other natural resources. The efficient use of available resources – as envisaged in CE – is therefore of central importance for the Swiss economy.

The KOF Enterprise Panel is a stratified random sample of 8000 Swiss companies that is representative of the population of companies. The stratification is done at the level of two-digit industries, geographic region and in each industry for three industry-specific firm size classes

⁴ All the information in this section is derived from reports (e.g., CSR report) available on the Tarkett website ([Link](#)), accessed June 2022.

⁵ The exact questions of the survey can be found in [Appendix A](#).

⁶ For more information on the KOF Enterprise Panel see: [KOF website](#).

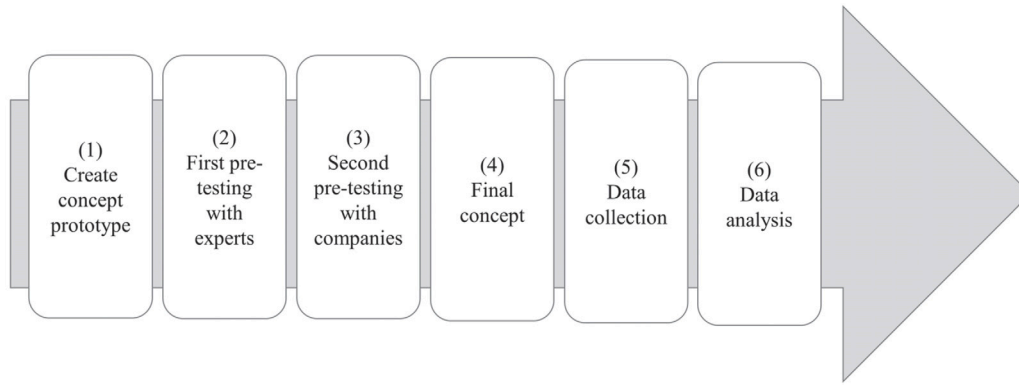


Fig. 1. Research flow chart.

(with full coverage of large firms).⁷ In addition, the data include specific contact persons for each company who are familiar with filling out such questionnaires and are well informed about the general business activities; usually these are the CEO, the CFO or the head of the R&D department. Since more than 99% of all companies in Switzerland are SMEs with fewer than 250 employees,⁸ these individuals usually have a good overview of the activities within the company and are therefore well suited to complete the questionnaire. To further ensure the representativeness of the data, an intensive round of reminders was conducted after the questionnaires were sent out. Distortions due to self-selection or non-response could thus be minimized. The response rate of 29.1% was satisfactory despite the difficult times during the Corona pandemic.

5. Empirical results

5.1. Current state of the transition

The data shows that the transition has just begun. 28% of companies have not implemented any circular economy activities at all in 2017–2019. 9% of companies have implemented more than 10 activities. Most companies have implemented activities in the areas of production (35%), procurement (29%), marketing/sales (23%), and internal storage/logistics (23%; see Table 1). Efficiency continues to be the main objective of the activities carried out; 54% of the companies have carried out activities to increase resource efficiency. Activities to close resource loops (44%) and to extend product life (34%) are implemented less frequently.

A similar picture emerges when looking at other indicators focusing on strategy, input and output (see Fig. 2). 12% of companies have integrated CE activities into their business model. 9% of companies invest more than 10% of their total investment in implementing CE activities, and 12% of companies generate more than 10% of their revenue from circular products/services. Thus, between 8% and 12% of Swiss companies are significantly involved in the transition to a CE.

In terms of geographic distribution, clusters of companies that are particularly active in integrating CE activities are represented throughout Switzerland (see Fig. A.1). The highest density of CE active firms

⁷ Depending on the weighting scheme chosen, the survey allows representative statements not only for Switzerland as a whole, but also at the two-digit industry level, the geographic region, and in each industry for three industry-specific firm size classes. For more details on stratification, sampling procedures, and weighting scheme, see Wörter and Spescha (2020). Additional information on the net sample and the response rate based on the various stratification characteristics of the KOF Enterprise Panel is presented in summary tables in Stucki and Wörter (2022), pp. 33–39 (in German).

⁸ For more information on the distribution of firm sizes in Switzerland see Bundesamt für Statistik, 2021 (in German).

Table 1

Share of firms that have implemented certain CE activities.

| CE activity | Share of firms |
|-----------------------------------|----------------|
| Procurement (29%) | |
| ● Footprint inputs | 19% |
| ● Used inputs | 9% |
| ● Footprint infrast. | 17% |
| ● Used infrast. | 6% |
| ● Infrast. for long life products | 13% |
| ● Life span infrastr. | 9% |
| ● Resale infrastr. | 19% |
| Design (20%) | |
| ● Product life | 9% |
| ● Repair | 6% |
| ● Updates/upgrades | 7% |
| ● Recycling | 7% |
| ● Pollution product use | 13% |
| Production (35%) | |
| ● Material use | 27% |
| ● Renewable energy | 12% |
| ● Pollution in production | 19% |
| ● Reusing waste | 15% |
| Storage/Logistics (23%) | |
| ● Reduce business travel | 9% |
| ● Optimize routing | 11% |
| ● Optimize warehouse | 13% |
| Sales (23%) | |
| ● Rental/leasing | 9% |
| ● Sharing platforms | 7% |
| ● Footprint documentation | 16% |
| After-sales (14%) | |
| ● Warranty | 9% |
| ● Spare parts | 6% |
| ● Range updates/upgrades | 7% |
| After-use (9%) | |
| ● Refunds | 7% |
| ● Resale products | 5% |

Notes: ●: efficiency, ●: closing resource loop, ●: increasing product life. This tables uses the short description of each circular economy business activity. For a long description of each activity see Table A.1.

extends along the area north-west of the alpine chain, with the largest concentration in Espace Mittelland, Central and Northwestern Switzerland, and Zurich. This is also reflected in the regional CE intensity, measured by the average CE activities taken over per company. Espace Mittelland and Zurich are the leading regions with about 4.5 CE activities integrated in an average company.

5.2. The transition process

By comparing companies with fewer CE activities with companies with many activities, it is also possible to characterize the transition

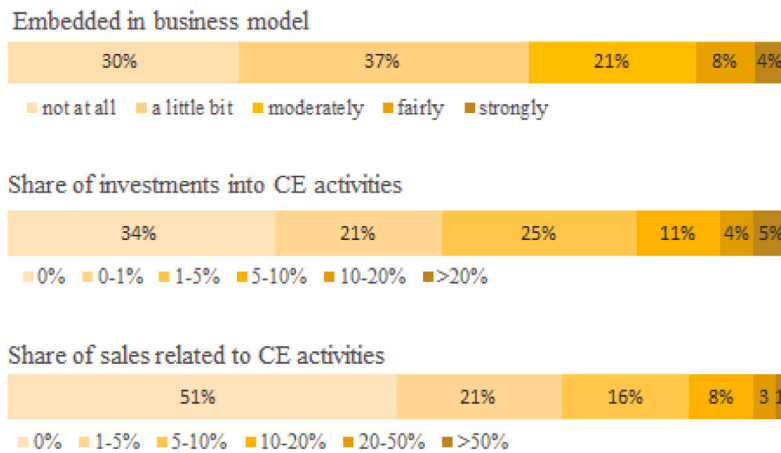


Fig. 2. Share of firms engaged in CE activities measured by different input output indicators.

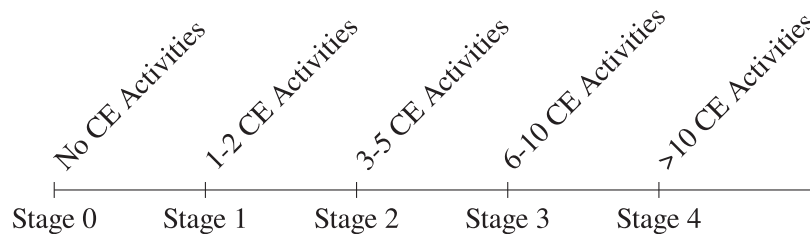


Fig. 3. Stages of transition.

process. The data suggest grouping companies into 5 stages of transition, roughly equal in size (see Fig. 3). Stage 0 consists of all companies in the sample that did not conduct CE activities (28%). Stage 1 includes all companies that have just begun the transition and have implemented between 1–2 CE activities (22%). Stage 2 includes companies that have implemented 3–5 CE activities (21%), while stage 3 includes companies with 6–10 CE activities (20%). Companies that are in stage 4, referred to as *pioneers*, have implemented more than 10 CE activities in 2017–2019 (9%).

It turns out that in a first stage (stage 1), companies focus mainly on activities in production to increase efficiency (see Fig. 4). In stage 2 the companies extend their (efficiency-increasing) activities particularly to procurement and consider also certain activities for the extension of the product life span. In stage 3, companies tend to adjust the product/service design and also consider activities in the after-sales area. In addition, activities to close loops are gaining importance. In stage 4, the spectrum extends to activities that increase the resale/upgrading of returned products, although these are implemented by only 5% of the companies in the overall sample. In general, efficiency-enhancing activities form the basis of CE activities are by far the most frequently implemented by companies. Another interesting finding is that the transition paths are relatively linear. If a particular activity is implemented frequently in one stage, it is likely to become much more widespread in the next transition stage.

Interestingly, the sectors do not differ significantly in the way they proceed with the transition. In construction, services, and manufacturing, efficiency-enhancing measures are relatively more important at the beginning, while life-extending measures and investments in closing material flows become more important later in the process (see Fig. A.2). However, a closer look at the 27 CE activities (see Fig. A.3) reveals some intuitive sector-specific characteristics. For example, companies operating in the (modern or traditional) service sector integrate proportionately more sales activities, while companies in the high-tech manufacturing sector focus proportionately more on adopting CE activities with regard to product design changes.

5.3. Identification of determining factors

Since the implementation of circular activities is essentially a question of innovation capability, the identification of the determining factors is based on broadly supported innovation models. Important explanatory variables in these models are export activities, innovation knowledge (“absorptive capacity”), company size, industry affiliation, competition intensity or financial resources. In addition, numerous other variables such as general company characteristics can be taken into account, which are potentially relevant for CE.

Following the innovation literature (see, e.g., Crepon et al., 1998; Cohen, 2010) and the adopted concept for the case of eco-innovation in Horbach et al. (2012), five dimensions are proposed to determine the adoption of CE activities. Fig. 5 highlights the five dimensions, three of which are standard in the innovation literature (knowledge, competition, financial resources) and two of which are particularly relevant for the CE and therefore complement existing concepts (digitalization, awareness).

Knowledge is a generic term for a company’s absorptive capacity (see among others Cohen and Levinthal, 1989, 1990; Zobel, 2017). The ability to absorb knowledge is critical for a company’s innovation performance, both in terms of resource inputs (i.e., R&D expenditures) and resource outputs (i.e., product or process innovations). It reflects not only a company’s innovation efforts per se, but also its ability to understand, transfer, and apply external knowledge internally. A company’s absorptive capacity was equated with its commitment to research and development in general and to product and/or process innovation in particular. In addition, absorptive capacity was approximated with the level of human capital and the proportion of employees with a corresponding level of education.

Financial resources are an important prerequisite for any kind of investment at the company-level, especially for risky innovation activities. Empirical evidence shows that companies primarily use internal resources rather than debt to finance innovation projects (see Leland and Pyle, 1977; Hall, 1989, 1992; Czarnitzki and Hottenrott, 2011). However, internal funds are inherently limited, and raising new equity

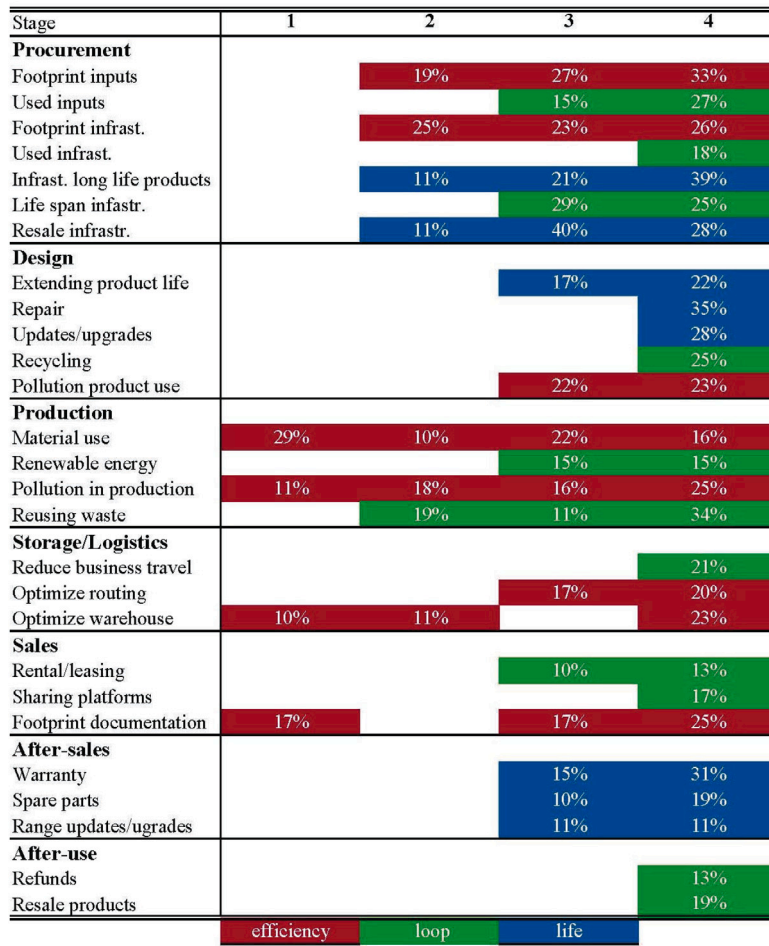


Fig. 4. Difference of adopting companies between stage (by CE activity).

Notes: Within each stage an area of a CE activity is coloured whenever the difference of adopting firms from one stage to another exceeds 10%. Stage 1: 1–2 CE activities, Stage 2: 3–5 activities, Stage 3: 6–10 activities, Stage 4: > 10 activities.

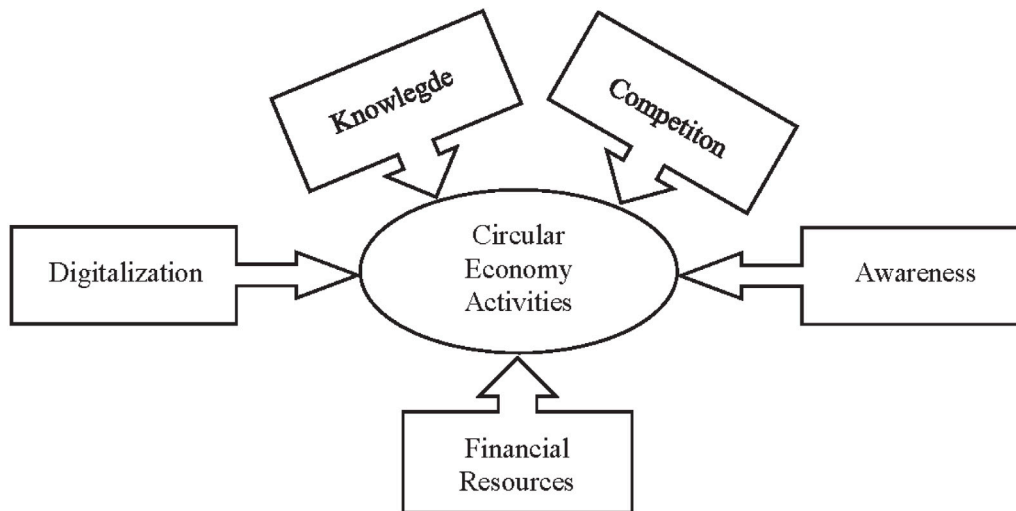


Fig. 5. Dimensions determining integration of CE activities.

can be costly and time-consuming. This has generated considerable interest in studying the impact of financial constraints on innovation performance (Hall et al., 1998; Canepa and Stoneman, 2008; Hall and Lerner, 2010; Hottenrott and Peters, 2012). Most studies conclude that binding financial constraints discourage innovation. Although the

relationship between financial resources and innovative CE activities is not yet clear, there is little reason to believe that the mechanism is different from general innovation activities. The intensity of CE investment and the level of cash flow are controlled to determine the company’s financial resources for CE activities. In the innovation

literature, cash flow is commonly used to analyse the sensitivity of investments to changes in available financial resources in order to identify financial constraints (see the seminal paper Fazzari et al., 1987).

Competition in a company's demand and supply markets is typically important for its innovation output. In the literature, the debate has largely focused on the effect of an increasing number of competitors due to trade liberalization on innovation activity (see, among others, Autor et al., 2016; Bloom et al., 2016; Baldwin and Gu, 2004). While the effect of market size on innovative activity of domestic companies is predominantly positive (see e.g., Acemoglu and Linn, 2004; Godin and Lane, 2013), the effect of competition on innovation output is ambiguous. A possible explanation is that competition measures largely vary widely in the literature.⁹ Most competition measures deal only with opening international markets, with a strong focus on the price-related competition environment. However, non-price competition – such as product differentiation, technical advancement, or flexibility in meeting customer needs – can play an equally important role, especially for highly innovative companies (Thompson and Woerter, 2020). As for general innovations, the competitive environment is also important for green and eco-innovations (Horbach et al., 2012; Stucki and Woerter, 2019) and is therefore likely to be important for CE as well.¹⁰ *Apriori*, however, the direction of the effect is not clear; because firms engaged in CE activities are likely to face different forms of competition, the model controls for both the intensity of price and non-price competition in which a company operates.

Awareness and a sense of social/environmental responsibility play a fundamental role in integrating sustainable business activities. Similarly, CE is not only a matter of capability (technological and financial), but also of motivation and the necessary understanding of its importance. There is evidence that companies with high energy intensity show a greater affinity to invest in green innovation, partly because efficient energy use is now one of the most discussed determinants regarding sustainability concerns (see e.g., Ley et al., 2016; Stucki, 2019). In addition, there is evidence that family-owned companies adopt greener practices because they respond differently to stakeholder pressure and thus to reputational concerns (Déniz and Suárez, 2005; Huang et al., 2009). The general corporate culture and attitudes towards green innovation, and thus towards CE activities, can also be partly explained by basic corporate characteristics such as the age and size of the company. Because larger and more established companies tend to have a stronger social impact due to the scale of their operations, they tend to feel a particular need to engage (Cowen et al., 1987; D'Amato and Falivena, 2020), even though their corporate structure may exhibit greater rigidity towards investing in socially responsible practices (Hannan and Freeman, 1984).¹¹ In addition, there is evidence that small – but fewer medium-sized – companies engage in corporate

⁹ Earlier studies mainly measured competition at the national level by C4 or C5 concentration ratios (Mansfield et al., 1981; Scherer, 1967), the 1-Learner index (Aghion et al., 2005), or the number of principal competitors (Peneder and Wörter, 2014; Peneder et al., 2020). Other studies that use more complex measures of competition include Boone (2001, 2008), Vives (2008).

¹⁰ Note that the competitive environment and a firm's competitiveness differ in that the former refers to the extent of competitive pressure from outside, while the latter describes the relative position of the individual firm within the competitive environment. The two may be related, and if so, it can be argued that reverse causality is possible. The competitive environment may influence the number of CE activities that a firm integrates, but at the same time the number of CE activities may also increase the firm's competitiveness (Stucki and Woerter, 2019) and thus have an impact on the relative perception of its competitive environment.

¹¹ In addition, some countries impose mandatory sustainability reporting, further increasing the pressure on (predominantly) larger companies to engage in CSR activities (see the Carrot and Sticks 2016 report on sustainability reporting instruments, <https://www.carrotsandsticks.net/reporting-instruments/>). For example, the U.K. government has introduced mandatory

social responsibility; mostly for strategic reasons (Madden et al., 2006; Udayasankar, 2008). However, because they often have more unpredictable cash flows, they are less likely overall to invest heavily in green innovation (Withisuphakorn and Jiraporn, 2016). In addition to the aforementioned determinants of awareness, the model also controls for the suitability of the company's business model to startup CE activities, which is expected to have a clear positive relationship. This variable is unique in the context of analysing eco-innovation in general and CE activities in particular.

Digitalization is expected to play a central role in the implementation of CE activities. Since the transition to a CE explicitly involves the entire production cycle, there should also be many complementarities. Digital technologies combined with creative thinking about the CE are basic prerequisites for bringing about fundamental changes across entire value chains (Rizos et al., 2017). Digital technologies can support waste reduction and improve resource efficiency in the context of CE (Schulze, 2016; PwC, 2019). In addition, the complexity of measuring the performance of CE activities also requires the use of digital technologies such as Big Data, sensors, 5G, IoT, robotics, Blockchain, and others. Therefore, companies are using advanced digital technologies to increase production efficiency, contribute to the efficient use of resources, and overall CE (Bressanelli et al., 2019). By using digital technologies to support CE practices, companies should be able to achieve sustainable environmental and socioeconomic benefits (Bag et al., 2020). It is evident that the CE paradigm and the digitalization of business are two closely intertwined phenomena that offer powerful opportunities for developing organizations and shaping their economic performance. The model controls the degree of digitalization within a company through the ICT share of investment or employment.

5.4. Characterizing the CE transition process

In order to better understand which factors can promote the transition to a CE, it is important to characterize in more detail the companies that already operate according to the circular principle. For this reason, multivariate regression analyses are conducted. The outcome variable used in these models is the number of implemented CE activities. In addition, the classification of companies into different stages of transition enables the identification of important characteristics in the course of the transition process. This provides information on whether certain determinants are particularly important in increasing the number of CE active firms in the transition process (extensive margin), as opposed to determinants that are particularly important in increasing the number of CE activities (intensive margin). Furthermore, because the fourth stage defines the pioneers in the data used, this approach makes it possible to draw conclusions about what makes the pioneers particularly distinctive in the transition to CE, which provides valuable information for the policy debate.

5.4.1. Empirical strategy

To characterize the transition process, the determinants are estimated in a first step based on a fractional logit estimation procedure, where the dependent variable is a restricted count variable ranging from 0 to 27 and can be easily transformed into a fractional dependent variable (Papke and Wooldridge, 1996; Wooldridge, 2010). Following the discussion of the determinants of CE activity in Section 5.3, the following fractional logit regression model is proposed:

$$E[CE\ Overall_i | \mathbf{x}_i] = \frac{\exp(\mathbf{x}_i' \beta)}{1 + \exp(\mathbf{x}_i' \beta)} \quad (1)$$

climate change reporting rules from April 2022 that (for now) apply only to large cooperations (see <https://www.geraldedelman.com/insights/the-uk-government-introduces-mandatory-climate-change-reporting-rules/>).

Table 2
Fractional logit/multinomial logit regression results (baseline = stage 4).

| | Stage | Model 1: Knowledge input | | | | | Model 2: Knowledge output | | | | | Model 3: ICT | | | | |
|-------------|----------------|--------------------------|----------------------|----------------------|----------------------|---------------------|---------------------------|----------------------|----------------------|----------------------|---------------------|---------------------|----------------------|----------------------|----------------------|---------------------|
| | | CE overall | 0 | 1 | 2 | 3 | CE overall | 0 | 1 | 2 | 3 | CE overall | 0 | 1 | 2 | 3 |
| Finances | CE invest | 0.031*** (0.003) | -0.893*** (0.102) | -0.485*** (0.085) | -0.129* (0.076) | -0.081 (0.073) | 0.028*** (0.003) | -0.840*** (0.101) | -0.438*** (0.084) | -0.123+ (0.076) | -0.063 (0.073) | 0.038*** (0.003) | -1.059*** (0.116) | -0.667*** (0.095) | -0.294*** (0.083) | -0.136* (0.077) |
| | cash-flow | | | | | | | | | | | 0.005** (0.002) | -0.242*** (0.068) | -0.101+ (0.069) | -0.173*** (0.067) | -0.163** (0.065) |
| Competition | export | 0.007 (0.009) | 0.034 (0.258) | 0.120 (0.249) | 0.073 (0.246) | 0.434* (0.244) | 0.002 (0.008) | 0.057 (0.251) | 0.273 (0.236) | 0.217 (0.233) | 0.467** (0.230) | 0.002 (0.010) | 0.157 (0.275) | 0.350 (0.265) | 0.211 (0.261) | 0.526** (0.259) |
| | foreign owned | -0.002 (0.011) | -0.274 (0.335) | -0.142 (0.305) | -0.253 (0.299) | -0.319 (0.301) | -0.004 (0.010) | -0.221 (0.329) | -0.031 (0.301) | -0.198 (0.293) | -0.305 (0.299) | -0.013 (0.012) | 0.052 (0.364) | 0.151 (0.332) | 0.158 (0.328) | -0.199 (0.334) |
| | price | 0.001 (0.004) | -0.055 (0.125) | 0.064 (0.122) | 0.048 (0.117) | 0.127 (0.120) | 0.001 (0.004) | -0.049 (0.129) | 0.044 (0.124) | 0.020 (0.116) | 0.113 (0.121) | 0.008* (0.005) | -0.231* (0.132) | -0.111 (0.128) | -0.086 (0.125) | -0.007 (0.125) |
| | non-price | 0.011*** (0.004) | -0.337*** (0.120) | -0.323*** (0.118) | -0.255** (0.112) | -0.246** (0.109) | 0.009** (0.004) | -0.276** (0.120) | -0.293** (0.118) | -0.238** (0.110) | -0.230** (0.108) | 0.012** (0.005) | -0.356*** (0.130) | -0.306** (0.124) | -0.192+ (0.122) | -0.202* (0.115) |
| Knowledge | R&D | 0.018* (0.010) | -0.595** (0.287) | -0.372 (0.273) | -0.134 (0.263) | -0.068 (0.260) | | | | | | 0.020* (0.011) | -0.781** (0.308) | -0.260 (0.292) | -0.166 (0.278) | -0.057 (0.278) |
| | higher edu | 0.000 (0.000) | -0.003 (0.009) | -0.004 (0.008) | -0.007 (0.008) | 0.001 (0.008) | | | | | | | | | | |
| | apprentices | 0.001* (0.001) | -0.027* (0.016) | -0.051*** (0.018) | -0.036* (0.019) | -0.023+ (0.016) | | | | | | | | | | |
| | vocational | 0.000 (0.000) | -0.011+ (0.007) | -0.005 (0.006) | -0.009 (0.006) | -0.003 (0.006) | | | | | | | | | | |
| | academ | 0.000 (0.000) | -0.012 (0.010) | 0.004 (0.009) | 0.003 (0.009) | -0.003 (0.009) | | | | | | | | | | |
| | product inno | | | | | | 0.051*** (0.008) | -1.274*** (0.250) | -0.924*** (0.236) | -0.700*** (0.229) | -0.484** (0.226) | | | | | |
| | process inno | | | | | | 0.031*** (0.008) | -0.998*** (0.237) | -0.546** (0.226) | 0.025 (0.220) | -0.274 (0.215) | | | | | |
| Awareness | business model | 0.063*** (0.010) | -1.735*** (0.339) | -1.663*** (0.305) | -1.046*** (0.251) | -0.337 (0.238) | 0.056*** (0.009) | -1.644*** (0.341) | -1.615*** (0.304) | -1.002*** (0.250) | -0.327 (0.236) | | | | | |
| | energy int | 0.016*** (0.006) | -0.313* (0.167) | -0.356** (0.160) | -0.178 (0.156) | 0.001 (0.146) | 0.017*** (0.006) | -0.315* (0.169) | -0.371** (0.162) | -0.193 (0.157) | 0.003 (0.146) | 0.016*** (0.006) | -0.293+ (0.187) | -0.354** (0.179) | -0.254+ (0.174) | 0.068 (0.164) |
| | age | -0.000 (0.006) | 0.093 (0.153) | 0.052 (0.149) | 0.128 (0.145) | 0.234* (0.142) | 0.003 (0.005) | 0.016 (0.153) | -0.017 (0.147) | 0.077 (0.138) | 0.198+ (0.135) | -0.004 (0.006) | 0.166 (0.162) | 0.148 (0.160) | 0.190 (0.155) | 0.245+ (0.150) |
| | family owned | 0.022** (0.009) | -0.424* (0.249) | -0.312 (0.242) | -0.491** (0.238) | -0.257 (0.237) | 0.021** (0.008) | -0.439* (0.248) | -0.388+ (0.239) | -0.553** (0.234) | -0.318 (0.232) | 0.016* (0.009) | -0.331 (0.264) | -0.383+ (0.254) | -0.301 (0.255) | -0.252 (0.251) |
| | company size | 0.019*** (0.003) | -0.490*** (0.102) | -0.334*** (0.095) | -0.248*** (0.094) | -0.188** (0.092) | 0.016*** (0.003) | -0.422*** (0.102) | -0.308*** (0.095) | -0.231** (0.093) | -0.157* (0.090) | 0.016*** (0.004) | -0.410*** (0.112) | -0.332*** (0.101) | -0.206** (0.102) | -0.172* (0.100) |
| Digit | digit (h/s) | | | | | | | | | | 0.008** (0.004) | -0.206* (0.106) | -0.100 (0.103) | -0.110 (0.103) | -0.071 (0.102) | |
| | digit (emp) | | | | | | | | | | 0.007* (0.004) | -0.085 (0.126) | -0.075 (0.123) | 0.201* (0.118) | 0.194* (0.117) | |
| | N | 1411 | | 1411 | | 1436 | | 1436 | | 1183 | | 1183 | | | | |
| | pseudo R2 | | | 0.13 | | | | 0.14 | | | | 0.13 | | | | |
| | Regional FE | YES | | YES | | YES | | YES | | YES | | YES | | YES | | |
| | Sector FE | YES | | YES | | YES | | YES | | YES | | YES | | YES | | |

+ $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust Standard errors in parentheses.

Table A.1
Overview of circular business activities.

| Short description | Long description |
|--|---|
| Procurement | |
| ● Footprint inputs | Reducing ecological footprint in production inputs |
| ● Used inputs | Increasing use of used production inputs (up-/downcycling) |
| ● Footprint infrast. | Reducing ecological footprint in production infrastructure |
| ● Used infrast. | Increasing purchase of used infrastructure |
| ● Infrast. long life products | Increasing purchase of infrastructure with a long product life |
| ● Life span infrastr. | Increasing the life span of the production infrastructure (repair, maintenance, etc.) |
| ● Resale infrastr. | Reselling unused infrastructure/materials |
| Product-/Service design for customers | |
| ● Product life | Extending product life |
| ● Repair | Facilitating repair during use |
| ● Updates/upgrades | Facilitating product updates/upgrades |
| ● Recycling | Facilitating recycling after use |
| ● Pollution product use | Reducing pollution in product use (i.e., energy consumption, air or noise pollution) |
| Internal production process | |
| ● Material use | Reducing material use in production (incl. packaging, paper) |
| ● Renewable energy | Increasing share of renewable energy in production |
| ● Pollution production | Reducing pollution in production process (i.e., energy consumption, air or noise pollution) |
| ● Reusing waste | Reusing waste products and residual materials inside or outside the company |
| Internal storage/logistics | |
| ● Reduce business travel | Increasing use of virtualization technology to reduce business travel |
| ● Optimize routing | Optimizing route selection (fuel efficiency) or fleet composition |
| ● Optimize warehouse | Optimizing logistics/warehouse concept to reduce storage space (size & duration) |
| Marketing/sales | |
| ● Rental/leasing | Increasing rental/leasing opportunities (<i>products as a service</i>) |
| ● Sharing platforms | Expanding the use of sharing platforms |
| ● Footprint documentation | Reducing ecological footprint of correspondence/product documentation |
| After-Sales services | |
| ● Warranty | Extending warranty or improved maintenance and repair services |
| ● Spare parts | Improving access to spare parts/equipment (lubricants, fuels, batteries) |
| ● Range updates/upgrades | Increasing range of product updates/upgrades |
| After-Use services | |
| ● Refunds | Refunds on product returns |
| ● Resale products | Resale/upgrade of returned products |

Notes: ●: efficiency, ●: closing resource loop, ●: increasing product life.

where the dependent variable $CE\ Overall_i \in [0, 1]$ describes the number of circular economy activities a firm i has integrated as a share of the total number of possible CE activities and $\mathbf{x}_i = \{x_i^{Finance}, x_i^{Comp}, x_i^{Knowl}, x_i^{Aware}, x_i^{Digi}\}$ contains different vectors of covariates related to the five dimensions: Financial Resources, Competition, Knowledge, Awareness and Digitalization. A detailed description of all covariates is provided in the summary statistics in Table A.2 and the correlation table in Table A.3.

In a second step, the categorization of the transition process into 5 stages is used to understand which determinants are particularly important in which phase of the transition. To this end, a multinomial logit regression of the 5 stages is proposed as follows (Cameron and Trivedi, 2005):

$$Pr(Stage_i = s) = \frac{\exp(\mathbf{x}'_i \beta_s)}{\sum_{k=0}^4 \exp(\mathbf{x}'_i \beta_k)} \quad \text{with } s \in \{0, 1, 2, 3, 4\} \quad (2)$$

In the multinomial regression analysis, pioneers (stage 4) are used as a base category to understand what particularly characterizes the pioneers group in the transition. This group is of particular interest because they serve as role models for others in the field, and their accumulated knowledge will help policymakers advance the transition process.

In general, the analyses should be understood as descriptive, since longitudinal information on firms' CE activities is lacking. Although the model includes an extensive vector of control variables that significantly reduces the risk of bias from omitted variables, it is not possible to present causal effects in the results section below.

5.4.2. Results

Table 2 contains the results of estimating Eqs. (1) and (2). Three different models are formulated for each estimation strategy: Knowledge Input, Knowledge Output, and ICT. They differ in terms of the vector of covariates and are estimated separately to avoid multicollinearity problems. The first column of each model reports the marginal effects of the fractional logit regression. The other four columns of each model contain the estimation results of the multinomial regression with base category stage = 4. In other words, the results of the multinomial regression are to be understood in terms of the group of pioneers, which explains the large number of negative coefficients throughout the model.

The fractional logit results suggest that companies exposed to non-price competition – such as product differentiation (customization), product quality, (frequent) introduction of new products, technical lead or flexibility in meeting customer needs and services – are more likely to implement measures to improve the circularity of their products and services than companies not exposed to such competition. Price competition, on the other hand, seems to be unrelated to integrating CE activities. This suggests that the type of competition, rather than competition per se, is an important factor for the transformation. Apart from the competitive environment, CE active companies differ in their awareness of circular opportunities, their innovative and absorptive capacity, as well as their internal availability of financial resources. The level of awareness is measured by company size, energy intensity, family ownership and the fact that they recognize the importance of the CE in their business model. All of these variables are significantly and positively related to the fraction of implemented measures, with 'business model' showing the strongest correlation. R&D-active companies and especially companies that can translate knowledge into commercially

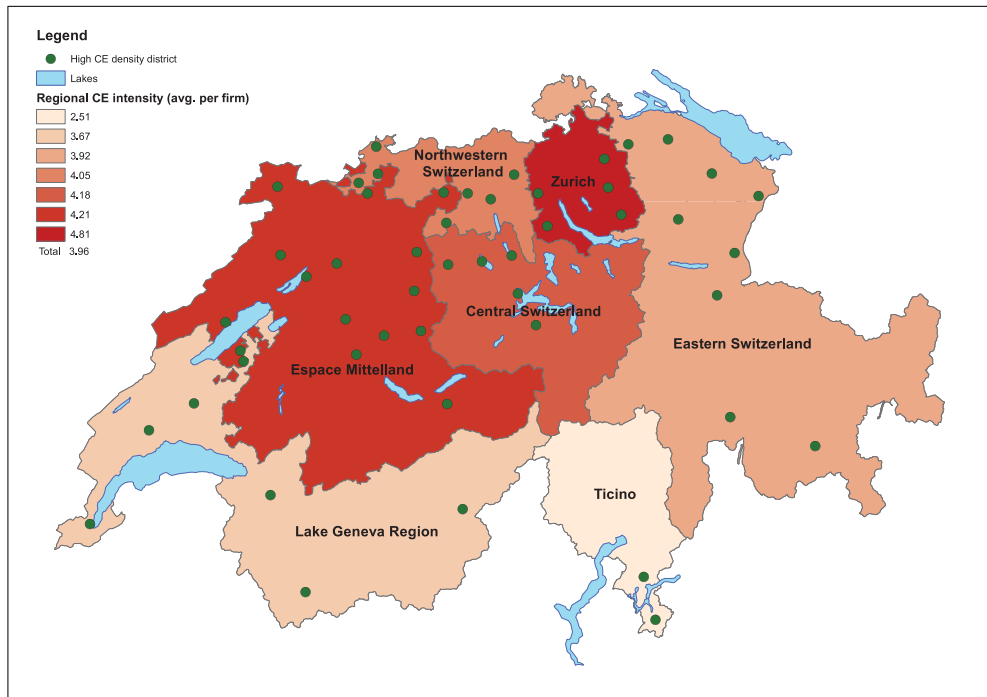


Fig. A.1. High CE-density areas across Switzerland.

Note: High CE-density areas are defined as the geographical centroid of the district which host at least one municipality in which the average firm has integrated a minimum of 10 CE activities.

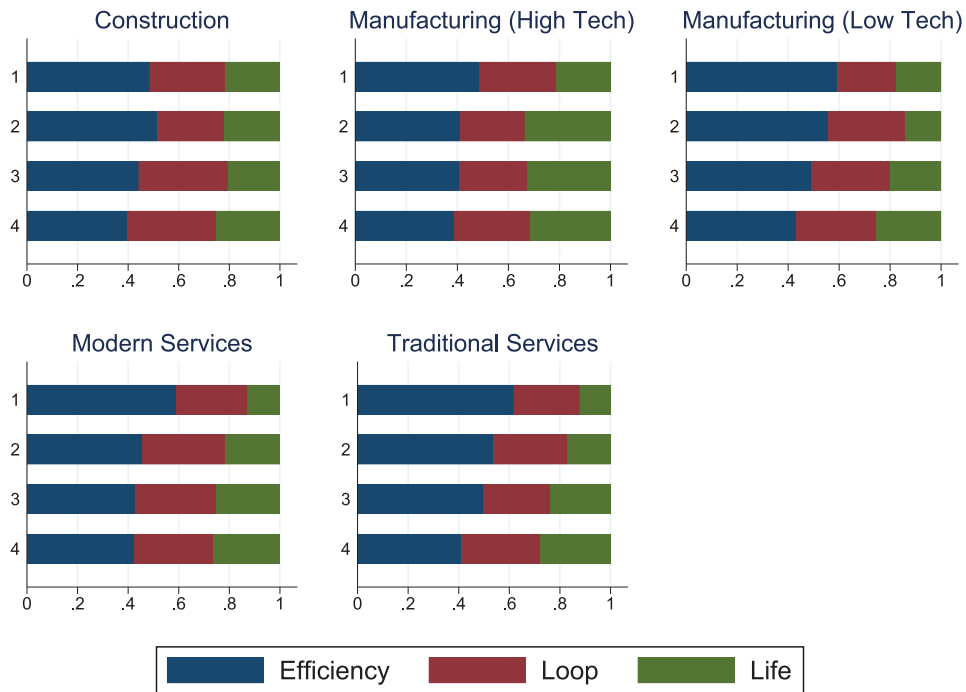


Fig. A.2. Share of efficiency/loop/life activities by stage and sector.

successful products and services are also among the early adopters of CE-measures. Besides awareness and innovation activity, the ability to invest in CE activities is one of the most important characteristics of CE-intensive companies. The positive effect of CE investment suggests that these companies are more likely to increase the breadth of measures at this early stage of CE, rather than investing heavily in a few measures.

Cash flow and, in particular, investment in the adoption of digital technologies are also characteristics of CE-intensive companies.

The multinomial regression results show which determinants are particularly important at each stage of the transition compared to the pioneers. Interestingly, a linear and significant increase in the importance of financial resources and exposure to non-price competition is



Fig. A.3. Share of CE activities by stage and sector.

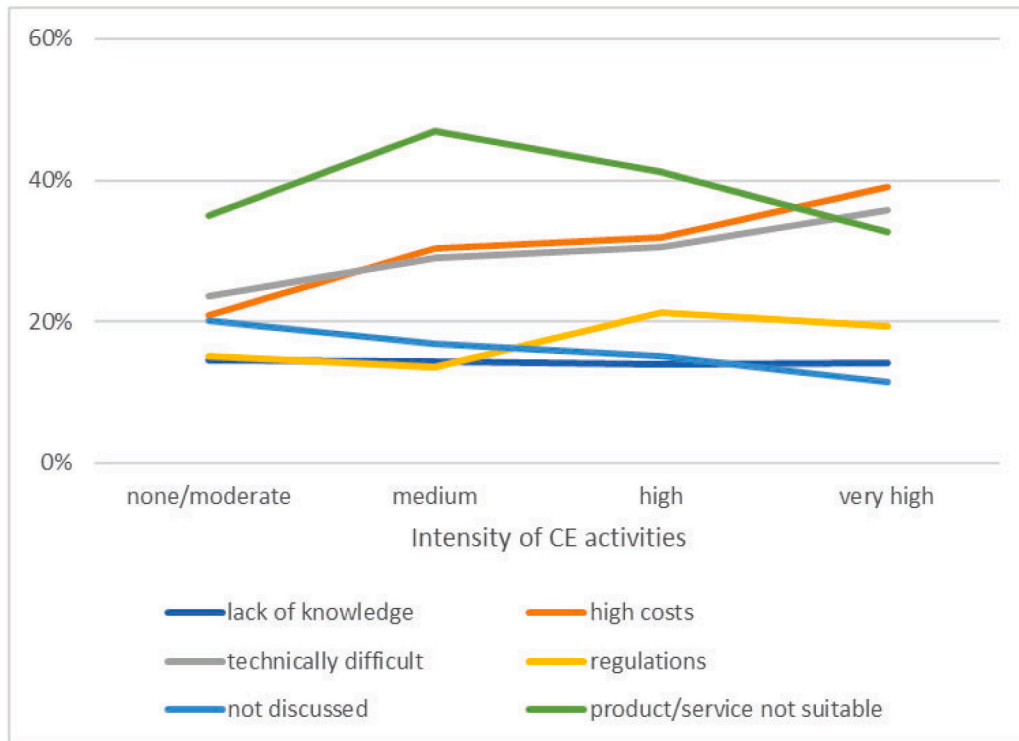


Fig. A.4. Proportion of firms heavily affected by a specific barrier (by intensity of implemented CE activities).

observed during the transition process. This is related to the fact that financial investment and market orientation are particularly important for intensive margin, i.e., to encourage firms to undertake *more* CE activities. Similarly, the level of CE awareness drives the intensity of CE activities, although no significant difference can be observed between the pioneers and the companies in stage 3. On the other hand, innovativeness and the level of digitalization seem to be important

prerequisites to start integrating CE activities and therefore mainly contribute to the increase of the extensive margin, i.e. the number of CE active companies.

Given that the economy is at the beginning of the transition process, the generation of *pioneers* is of particular importance. These companies challenge the frontiers while serving as role models for other companies. They may require special market conditions, which

Table A.2
Summary statistics.

| Variable | Description | Obs | Mean | Std. Dev. | Min | Max |
|-----------------------|--|------|-------|-----------|------|-------|
| CE overall | Share of adopted CE activities w.r.t total | 1961 | .15 | .16 | 0 | 1 |
| Finance | | | | | | |
| CE invest | Intensity in CE investments | 1751 | 2.65 | 1.37 | 1 | 6 |
| cash-flow | Available cash flow (in logs) | 1651 | 10.74 | 1.93 | 0 | 15.58 |
| Competition | | | | | | |
| export | Firm is an exporter (0/1) | 2269 | .41 | .49 | 0 | 1 |
| foreign owned | Foreign ownership (0/1) | 2264 | .14 | .35 | 0 | 1 |
| price comp | Intensity of exposure to price competition | 2206 | 3.91 | 1.02 | 1 | 5 |
| non-price comp | Intensity of exposure to non-price competition | 2142 | 3.13 | 1.01 | 1 | 5 |
| Knowledge | | | | | | |
| R&D | Firm is active in R&D (0/1) | 2190 | .28 | .45 | 0 | 1 |
| higher edu | Share of employees with higher education | 2290 | 16.18 | 15.51 | 0 | 100 |
| apprentices | Share of apprentices among employees | 2290 | 5.17 | 6.97 | 0 | 100 |
| vocational | Share of employees in vocational training | 2290 | 44.55 | 24.15 | 0 | 100 |
| academ | Share of employees with academic degree | 2290 | 14.26 | 18.69 | 0 | 100 |
| product inno | Firm is active in product innovation (0/1) | 2290 | .4 | .49 | 0 | 1 |
| process inno | Firm is active in process innovation (0/1) | 2290 | .42 | .49 | 0 | 1 |
| Awareness | | | | | | |
| business-model | Business model suited for CE activities (0/1) | 1739 | .16 | .37 | 0 | 1 |
| energy int | Energy cost share (in logs) | 2290 | .93 | .7 | 0 | 4.51 |
| age | Firm age (in logs) | 2248 | 3.79 | .84 | 0 | 6.22 |
| family owned | Firm is family owned (0/1) | 2226 | .56 | .5 | 0 | 1 |
| company size | Number of employees (in logs) | 2290 | 3.88 | 1.37 | 1.61 | 10.54 |
| Digitalization | | | | | | |
| digit (h/s) | ICT share in investments (in logs) | 2102 | 2.09 | 1.31 | 0 | 4.62 |
| digit (emp) | ICT share in employment (in logs) | 2290 | .91 | 1.1 | 0 | 4.62 |

Notes: To avoid missing values when transforming the variables into logarithms, the value 1 is added to each observation. Variables *CE invest*, as well as *price comp* and *non-price comp* are categorical variables ranging from 0 to 6 or 0 to 5, respectively. Non-price comp: competitive situation in which the following dimensions are important for competitiveness: product differentiation (“customization”), product quality, (frequent) introduction of new products, technical lead, flexibility in meeting customer requirements, services.

this paper aims to identify so that policymakers can better target the necessary measures to support the transition. The results suggest that pioneers are, on average, larger firms that face non-price competition, successfully commercialize new products, and have the financial resources to invest in CE activities. Following the descriptive statistics, the regression results also confirm that pioneers in Switzerland are relatively evenly distributed across regions and sectors.¹² This suggests that there does not appear to be an underlying regional or sector-specific mechanism that explains the existence of pioneers within the economy. Rather, overall business characteristics, as well as the market environment, seem to predominantly determine the introduction of CE activities.

6. Conclusion

This paper develops a concept for empirically measuring the transition process to a CE at the company level. The concept distinguishes between 27 CE-relevant business activities, based on which data were collected in a representative survey of 8000 Swiss companies. This makes it possible for the first time to present a representative picture of the circular activities of private companies in a national economy. The data are analysed using descriptive statistics and simple regression analysis to understand how far the transformation has progressed and how it could potentially be further advanced.

¹² Due to limited sectoral variation within the different stages, the sectoral fixed effects in the main regression in Table 2 only distinguish between construction, modern and traditional services, and high-tech and low-tech manufacturing. For robustness, the fractional logit regressions were run again with a finer sector specification (i.e., fixed effects for 34 two-digit industry classes), and the results are compared in Table A.4. The results are quantitatively and qualitatively very similar, which was taken as evidence that there is no underlying mechanism within sectors.

The data show that the transition to a CE in Switzerland has just begun. To date, companies have focused primarily on efficiency-enhancing CE measures, but even these are not currently being implemented on a large scale. More typical CE activities that focus on preserving the value and utility of object and material inventories are implemented even less frequently. The companies that are particularly active in taking CE action are distinguished primarily by their willingness to invest a significant amount of their capital, having the necessary financial resources, demonstrating significant absorptive capacity (in terms of innovative activities), and showing significant awareness of social/environmental business practices.

While the concept of CE has arrived in politics and in the media, it can be noted that the transition of the private sector of the economy in this direction is still in its infancy. Although market-based processes can support the transition process (see McAfee, 2019), additional economic policies are needed to reduce the major barriers to the transition process and to achieve environmental goals in a reasonable timeframe. So what can be done to stimulate this process?

First, CE transition is often hampered by a *lack of suitability* of products and services. The survey also collected information on the main barriers to integrating the activities of CE (see Question 4 in Appendix A). 38% of companies stated that their products/services are not suitable for such CE activities, with little difference between sectors. Moreover, this barrier decreases only slightly with the intensity of CE activities (see Fig. A.4), indicating that they see only moderate learning opportunities, which is also confirmed by the fact that they do hardly complain about a lack of general knowledge; lack of knowledge is a main barrier for only 14% of the companies. So companies seem stuck in the linear business models they have built over the years. Communicating best practices may be one way to challenge their linear business models. To support more experienced businesses, appropriate education and training programs could be created that focus specifically on CE. Young people should be familiarized with the concept of CE during their education so that CE becomes more and more the *new normal*. Networks could be established in which companies can

Table A.3
Cross-correlation table.

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | |
|--------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|------|------|--|
| 1 CE overall share | 1.00 | | | | | | | | | | | | | | | | | | | | | |
| 2 CE invest | 0.39 | 1.00 | | | | | | | | | | | | | | | | | | | | |
| 3 cash-flow | 0.05 | 0.06 | 1.00 | | | | | | | | | | | | | | | | | | | |
| 4 export | 0.10 | 0.09 | 0.01 | 1.00 | | | | | | | | | | | | | | | | | | |
| 5 foreign owned | 0.02 | 0.03 | 0.02 | 0.18 | 1.00 | | | | | | | | | | | | | | | | | |
| 6 price | 0.07 | 0.06 | -0.07 | 0.00 | 0.03 | 1.00 | | | | | | | | | | | | | | | | |
| 7 non-price | 0.10 | 0.06 | -0.03 | 0.10 | 0.04 | 0.29 | 1.00 | | | | | | | | | | | | | | | |
| 8 R&D | 0.19 | 0.17 | 0.00 | 0.41 | 0.05 | 0.02 | 0.12 | 1.00 | | | | | | | | | | | | | | |
| 9 higher edu | -0.02 | 0.00 | 0.07 | 0.05 | 0.07 | -0.03 | 0.05 | 0.05 | 1.00 | | | | | | | | | | | | | |
| 10 apprentices | 0.02 | 0.00 | -0.05 | -0.17 | -0.11 | 0.12 | -0.03 | -0.08 | -0.10 | 1.00 | | | | | | | | | | | | |
| 11 vocational | 0.03 | -0.03 | 0.01 | -0.13 | -0.09 | 0.01 | -0.03 | -0.11 | -0.37 | 0.07 | 1.00 | | | | | | | | | | | |
| 12 academ | -0.04 | -0.03 | 0.02 | 0.18 | 0.14 | -0.09 | 0.06 | 0.16 | 0.11 | -0.14 | -0.47 | 1.00 | | | | | | | | | | |
| 13 product inno | 0.25 | 0.17 | 0.05 | 0.26 | 0.10 | 0.04 | 0.11 | 0.42 | 0.05 | -0.08 | -0.05 | 0.09 | 1.00 | | | | | | | | | |
| 14 process inno | 0.24 | 0.22 | 0.02 | 0.14 | 0.01 | 0.08 | 0.10 | 0.17 | 0.05 | 0.00 | -0.06 | 0.09 | 0.23 | 1.00 | | | | | | | | |
| 15 business-model | 0.30 | 0.28 | 0.07 | 0.06 | 0.02 | 0.03 | 0.05 | 0.12 | 0.05 | -0.03 | -0.03 | 0.09 | 0.12 | 0.15 | 1.00 | | | | | | | |
| 16 energy int | 0.08 | 0.13 | -0.03 | -0.04 | -0.04 | -0.06 | -0.04 | -0.01 | -0.12 | -0.04 | 0.03 | -0.12 | -0.02 | -0.03 | -0.01 | 1.00 | | | | | | |
| 17 age | 0.11 | 0.12 | 0.03 | 0.08 | -0.05 | 0.11 | -0.02 | 0.07 | -0.03 | 0.12 | 0.10 | -0.15 | 0.03 | 0.04 | -0.01 | 0.03 | 1.00 | | | | | |
| 18 family owned | 0.04 | 0.03 | -0.09 | -0.01 | -0.15 | 0.16 | 0.02 | -0.01 | -0.12 | 0.06 | 0.11 | -0.26 | -0.02 | -0.01 | -0.06 | 0.08 | 0.08 | 1.00 | | | | |
| 19 company size | 0.26 | 0.18 | 0.04 | 0.20 | 0.15 | 0.09 | 0.06 | 0.22 | -0.01 | -0.02 | 0.00 | 0.02 | 0.17 | 0.20 | 0.15 | -0.03 | 0.29 | -0.15 | 1.00 | | | |
| 20 digit (h/s) | 0.12 | 0.13 | -0.02 | 0.14 | 0.03 | 0.06 | 0.07 | 0.14 | 0.13 | 0.00 | -0.06 | 0.21 | 0.12 | 0.19 | 0.09 | -0.10 | 0.06 | -0.05 | 0.18 | 1.00 | | |
| 21 digit (emp) | 0.10 | 0.08 | 0.05 | 0.18 | 0.08 | -0.03 | 0.08 | 0.20 | 0.15 | -0.06 | -0.18 | 0.37 | 0.16 | 0.14 | 0.07 | -0.06 | -0.02 | -0.17 | 0.21 | 0.29 | 1.00 | |

Table A.4
Robustness: Fractional logit regressions with industry FE (marginal effects).

| | Knowledge input | | Knowledge output | | ICT | |
|----------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| | CE overall | CE overall | CE overall | CE overall | CE overall | CE overall |
| CE invest | 0.031*** (0.003) | 0.030*** (0.003) | 0.028*** (0.003) | 0.027*** (0.003) | 0.038*** (0.003) | 0.037*** (0.003) |
| cash-flow | | | | | 0.005** (0.002) | 0.006*** (0.002) |
| export | 0.007 (0.009) | 0.007 (0.010) | 0.002 (0.008) | 0.002 (0.009) | 0.002 (0.010) | 0.004 (0.010) |
| foreign owned | -0.002 (0.011) | 0.001 (0.011) | -0.004 (0.010) | -0.002 (0.010) | -0.013 (0.012) | -0.007 (0.012) |
| price | 0.001 (0.004) | -0.001 (0.004) | 0.001 (0.004) | -0.001 (0.004) | 0.008* (0.005) | 0.006 (0.005) |
| non-price | 0.011*** (0.004) | 0.009** (0.004) | 0.009** (0.004) | 0.008** (0.004) | 0.012** (0.005) | 0.010** (0.005) |
| R&D | 0.018* (0.010) | 0.020* (0.010) | | | 0.020* (0.011) | 0.022** (0.011) |
| higher edu | 0.000 (0.000) | 0.000 (0.000) | | | | |
| apprentices | 0.001* (0.001) | 0.001** (0.001) | | | | |
| vocational | 0.000 (0.000) | 0.000 (0.000) | | | | |
| academ | 0.000 (0.000) | 0.000 (0.000) | | | | |
| product inno | | | 0.051*** (0.008) | 0.051*** (0.008) | | |
| process inno | | | 0.031*** (0.008) | 0.030*** (0.008) | | |
| business-model | 0.063*** (0.010) | 0.065*** (0.010) | 0.056*** (0.009) | 0.059*** (0.009) | | |
| energy int | 0.016*** (0.006) | 0.018*** (0.006) | 0.017*** (0.006) | 0.018*** (0.006) | 0.016*** (0.006) | 0.017** (0.007) |
| age | -0.000 (0.006) | 0.001 (0.006) | 0.003 (0.005) | 0.003 (0.005) | -0.004 (0.006) | -0.003 (0.006) |
| family owned | 0.022** (0.009) | 0.019** (0.009) | 0.021** (0.008) | 0.019** (0.008) | 0.016* (0.009) | 0.012 (0.009) |
| company size | 0.019*** (0.003) | 0.019*** (0.003) | 0.016*** (0.003) | 0.016*** (0.003) | 0.016*** (0.004) | 0.015*** (0.004) |
| digit (h/s) | | | | | 0.008** (0.004) | 0.008* (0.004) |
| digit (emp) | | | | | 0.007* (0.004) | 0.009* (0.005) |
| N | 1411 | 1411 | 1436 | 1436 | 1183 | 1183 |
| Region FE | YES | YES | YES | YES | YES | YES |
| Sector FE | YES | | YES | | YES | |
| Eco classes FE | | YES | | YES | | YES |

+ $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors in parentheses.

share their experiences or exchange knowledge with public research institutions.

Second, more *technological knowledge* is needed. 29% of companies see the technical feasibility of CE activities as a major barrier, and this is becoming more evident as companies become more engaged in implementing CE. In order to reduce technological barriers, technology transfer from universities to companies could be improved and specific programs to promote innovation could be introduced. In addition, improved exchange between companies also seems to be of key importance. Above all, cooperation between companies (across national borders) can help spread the often high development costs among several companies.

Third, *economic incentives* must be created so that such a transition pays off economically for companies. Only if this is the case will companies be willing to transition on a large scale and quickly. Currently, 29% of companies in the sample used indicate that high investment costs are a very important barrier to implementing such CE activities, and this becomes even more important as companies progress in their CE activities. A mix of policy instruments is needed to reduce this barrier (Popp, 2019). Taxes that internalize external costs are generally preferable. However, regulatory intervention will also be needed to

accelerate the transition. To reduce transition costs, more research is also needed to better understand the mechanisms and drivers of CE. For example, digitalization is believed to be an important driver of the transition to a CE and can also significantly reduce implementation costs. However, there are hardly any corresponding empirical studies that show exactly how the interaction of these two main players works.

Politicians seem to become increasingly aware of their role in the process of transformation. More and more political efforts to support the CE transition can be observed. For example, the European Commission's CE Action Plan is one of the key building blocks of the European Green New Deal — Europe's new agenda for sustainable growth (EU, 2020a). To increase the effectiveness of these policies, more knowledge is needed about where CE transition actually stands and in which areas improvements are needed. In addition to the information already available on recycling rates, company-level indicators such as those collected for Switzerland seem particularly useful for this purpose. Ideally, such information would be collected for different countries and with some regularity. Only if progress can be compared between countries and over time can policy be adjusted effectively. For example, the EU has now introduced *the right to repair* for the owner/users of products, and the obligation for manufacturers to provide spare

parts, tools and access to information for a period of ten years after production of a specific product has stopped (EU, 2020a). Based on current indicators, it will be quite difficult to measure the impact of such a policy. After all, CE activities are not necessarily associated per se with positive economic and environmental impacts. To improve policy interventions, there is a need to improve the understanding of which activities have a positive impact on economic and environmental performance.

While this study marks an important (and long over-due) steppingstone towards the understanding of how companies progress in adapting CE activities, it is (currently) limited to cross-sectional data for one single economy. For future research, it would be desirable to follow the firm level progress in an economy over multiple years and gain a deeper understanding of the importance of each dimension — with the possibility to determine causal effects. Furthermore, it would be worthwhile to adopt the concept for data collection and analysis to other economies to shed more light on the importance of the institutional environment through cross-country comparisons.

Finally, the mechanisms driving CE need to be better researched. What exactly are the factors driving CE? Do the factors differ between countries, and possibly even between companies? For example, an in-depth analysis of digitalization seems relevant. While digitalization is generally regarded as an enabler of CE, there is yet little empirical evidence on which factors of digitalization exactly influence which areas of CE. Moreover, there is an exiting research opportunity to better understand the ecological and economic effects of CE in greater depth. It is implicitly assumed that CE has a positive impact on the ecological and economic performance of companies. However, whether this is really the case, and whether this applies to all areas of CE, is still unclear.

CRedit authorship contribution statement

Tobias Stucki: Conceptualization, Investigation, Methodology, Formal analysis, Writing – original draft & review. **Martin Woerter:** Conceptualization, Investigation, Resources, Methodology, Formal analysis, Writing – original draft. **Nicole Loumeau:** Formal analysis, Visualization, Writing – original draft.

Data availability

The data that has been used is confidential.

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Appendix A. Survey questions

Disclaimer: The original questionnaire was conducted in German. The questions presented hereafter were translated by the authors. The original questions in German can be obtained upon request.

Circular business activities

1. During the years 2017–2019, did you achieve any measurable changes within your company in the following areas (I–VII)?

I Procurement yes no

If yes, tick the appropriate boxes; multiple choices possible

(a) Concerning production inputs

- Reducing the ecological footprint of new purchases (e.g., for production, transport)

- Increasing use of used production inputs (up/downcycling)

(b) In production infrastructure (e.g. buildings, machinery)

- Reducing the ecological footprint of new purchases (production, transport)
- Increasing purchase of used infrastructure
- Increasing purchase of infrastructure with a long product life
- Activities to increase the life span of the production infrastructure used internally (repair, maintenance, etc.)
- Resale of unused infrastructure/materials

II Product/ Service design for customers yes no

If yes, tick the appropriate boxes; multiple choices possible

- Extending product life
- Facilitating repair during use
- Facilitating product updates/upgrades
- Facilitating recycling after use
- Reducing environmental pollution during use/by use (energy consumption, water, soil, air or noise pollution)

III Internal production process yes no

If yes, tick the appropriate boxes; multiple choices possible

- Reducing material consumption (including packaging, paper) in the production process
- Increasing use of renewable energy sources in production
- Reducing environmental pollution in the production process (energy consumption, water, soil, air or noise pollution)
- Reusing waste products and residual materials inside or outside the company

IV Internal storage/logistics yes no

If yes, tick the appropriate boxes; multiple choices possible

- Increasing use of virtualization technology to reduce business travel
- Improving the ecological footprint by optimizing route selection (fuel efficiency) or fleet composition
- Optimizing the logistics/warehouse concept to reduce the required storage space (area and duration)

V Marketing/Sales yes no

If yes, tick the appropriate boxes; multiple choices possible

- Expanding rental/leasing opportunities (Products as a Service)
- Expanding sharing platforms
- Reducing the ecological footprint of correspondence/product documentation

VI After-Sales Services yes no

If yes, tick the appropriate boxes; multiple choices possible

- Extending the warranty or improved maintenance and repair services
- Improving access to spare parts/equipment (lubricants, fuels, batteries)
- Increasing range of product updates/upgrades

VII After-Use Services yes no

If yes, tick the appropriate boxes; multiple choices possible

- Refunds on product returns
- Resale/upgrade of returned products

2. Importance of circular business activities

- How large were your investments in circular business activities (see I–VII) as a share of total investments

- 0%
- 0%–1%
- 1%–5%
- 5%–10%
- 10%–20%
- > 20%

- How large was the share of sales in products/services regarding the activities implemented in II ?

- 0%
- 1%–5%
- 5%–10%
- 10%–20%
- 20%–50%
- >50%

3. Organization of circular business activities

- Is the increased integration of these activities (I–VII) centrally governed within your company?

- yes
- no

- How strongly are these activities (I–VII) embedded in your business model?

- not at all
- a little bit
- moderately
- fairly
- strongly

4. Barriers regarding circular business activities

- Which factors hinder the integration of circular business activities in your company?

Scale 1–5: from not at all hindering (1) to very much hindering (5)

| | 1 | 2 | 3 | 4 | 5 |
|---------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Lack of knowledge | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| High costs | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Technically difficult | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Regulations | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| So far not been discussed | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Product/Service is not suitable | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

Appendix B. Additional tables and figures

See Table A.1 and Figs. A.1–A.4.

Appendix C. Descriptive statistics

See Tables A.2 and A.3.

Appendix D. Robustness

See Table A.4.

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