Learning from the Best: How Regional Knowledge Stimulates Circular Economy Transition at Company Level

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Abstract: This paper investigates whether, and what kind of, regional knowledge has a stimulating effect on circular economy innovation by companies. We thus add to the literature on regional knowledge spillovers, which has rarely focused explicitly on the circular economy. For the empirical study, we create econometric regressions based on a representative dataset with extensive information on the circular economy activities of about 1,400 Swiss firms. The results confirm that regional knowledge is important for the implementation of circular economy innovations. However, geographical distance and the quality of the knowledge must be taken into account, i.e. companies primarily learn from the best.

Keywords: circular economy; sustainability transition; regional knowledge spillover; anchor tenant; company level data; quantitative analysis.

JEL classification: O30, O33, Q55

Introduction

If we want to tackle our environmental problems successfully, there is no way around the circular economy (CE). Around 50% of CO2 is generated by the materials economy (OECD, 2019). It is therefore very important to make materials management more efficient in the future. This is the goal of the CE: to minimize the amount of waste by using existing resources as long and as efficiently as possible (Esposito et al., 2017). To achieve this goal, a CE makes innovative adjustments to products, services and processes along the entire value chain.

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However, we are still in the early stages of the transition to a CE. Every year, 100 billion tons of materials are consumed worldwide; in 2020, only 8.6% of materials were returned to the economy after use (Circle Economy, 2023). The picture is no different at company level. Based on representative company data for Switzerland, Stucki & Woerter (2021) find that only 10% of companies invest significantly in CE activities.

On a positive note, however, there are certainly companies that are already well advanced in CE and show that it can be successfully implemented. These include global companies such as Patagonia, Hilti, Caterpillar and Philips. But there are also such pioneers at regional level. For Switzerland, Stucki et al. (2023) find that there are regional clusters of companies throughout Switzerland that are particularly active in the integration of CE activities.

To understand the prominent role that certain regions play in the transition to a CE, it is essential to look at the specific regional circumstances that support this transformation process. Tapia et al. (2021) emphasize the need for "the identification of spatial regimes and territorial dynamics linked to circular economic transformations". As the transformation to the CE is linked to innovation (Horbach & Rammer, 2020; Scarpellini et al., 2020), we draw on theories of innovation-based regional development to provide explanations. Therefore, we link directly to the literature on regional knowledge spillovers, which argues that firms do not innovate in isolation, but draw on pre-existing external knowledge to create new knowledge.

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While this literature is relatively extensive for general innovation (for example: innovative milieux (Camagni, 1991), learning regions (Florida, 1995), regional innovation systems (Autio, 1998), knowledge spillovers (Bottazzi & Peri, 2003), clusters (Porter, 2003), proximities (Boschma, 2005), local buzz (Bathelt et al., 2004), this topic has not yet been empirically investigated for the CE. It is assumed that CE innovations are more complex, as the transition from a linear to a circular business model requires adjustments to existing supply chains, the creation of new networks, the consideration of new technologies and organizational adjustments (e.g., Bocken et al., 2016; De Schoenmakere et al., 2019).

Building on the findings from the literature on knowledge spillovers, we also recognize the critical importance of knowledge spillovers from leaders to followers (Eeckhout & Jovanovic, 2002). In addition, the influence of geographical proximity to other companies is recognized as a catalyst for knowledge spillovers (for example Malerba et al., 2013). These earlier findings underline the interconnectedness of spatial dynamics, knowledge transfer and regional clustering in the promotion of CE innovations in specific geographical contexts.

In this paper, we want to learn more about the role of leading companies in the transition to a CE and specifically focus on the role of regional knowledge spillovers and how geographical proximity influences the exchange of CE knowledge. This paper therefore aims to make a theoretical contribution to the exploration of how geographical distance influences knowledge spillovers and innovation in the CE context. It also aims to explore the importance of regional CE leaders in facilitating knowledge spillovers at the regional level.

For the empirical analysis of these questions, we use one of the world's first quantitative datasets that comprehensively maps the CE at the firm level. The dataset is representative of the Swiss corporate structure and allows for a quantitative analysis of CE activities at the firm level. The data is based on the KOF (Swiss Economic Institute) Innovation Survey, which represents a sample of around 8,000 companies. A specific concept was developed for the identification of CE activities (see Stucki et al., 2023), which allows such activities to be measured in a very differentiated manner.

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Conceptual background

This section outlines the theoretical background for the role of regional knowledge spillovers in the context of CE innovation. Our exploration will focus on the dual facets of general innovation knowledge and specialized CE knowledge. Furthermore, we will scrutinize the influence of geographical distance on knowledge spillovers and delve into the pivotal role that leading companies play in fostering CE innovation within a given region.

CE is a broad concept that explicitly considers activities along the entire production cycle and focuses on the efficient use of existing resources and the closing of resource flows. There is a consensus in the literature that the implementation of CE is quite complex and requires partnerships, alliances, and knowledge linkages (e.g., Bocken et al., 2016; De Schoenmakere et al., 2019). Nevertheless, CE has not yet received much attention in the innovation literature. However, there is a strand that deals with how knowledge affects "green innovations", i.e. innovations that are associated with a positive environmental effect. While the literature on green innovation focuses heavily on product innovation and the production phase, CE is a broader concept that considers the entire supply chain from procurement to after-use activities (de Jesus & Mendonça, 2018; Geissdoerfer et al., 2018). Due to the complexity of CE innovation, the theories and concepts in the general and green innovation literature are not 1:1 transferable to CE and need to be further specified (Jakobsen et al., 2021). Nevertheless, to formulate hypotheses regarding regional knowledge spillovers in the CE, we primarily turn to the body of literature centred on green innovations. This strand of literature is more closely related than the general innovation literature, as green innovation and CE innovation share the common goal of promoting environmental sustainability, are considered more complex and require more knowledge acquisition than traditional technologies (Barbieri et al., 2020).

Regional knowledge spillovers in the CE

The concepts of innovative milieux, learning regions, clusters, local buzz and proximities share the idea that geographical proximity facilitates and enables collaboration, interaction and the sharing of knowledge and information (Bathelt et al., 2004; Boschma, 2005; Moulaert & Sekia, 2003). In addition, geographical proximity to other firms enables the maintenance of informal relationships with other firms in the region, which is considered one of the main reasons for the spatial concentration of innovation activities (Storper, 1997). Based on these literatures, it can be assumed that regionally available knowledge promotes the implementation of innovations in a company. This is also true for green innovations; for example, Aghion et al. (2016) and Stucki & Woerter (2017) find evidence for regional knowledge spillovers in green innovations. Moreover, the findings of Stucki & Woerter (2022) suggest that external knowledge has a stronger influence on green innovation than non-green innovation. Kok et al. (2021) find that companies that use more external knowledge and adopt more open innovation practices are more likely to adopt green process innovations. As for the specific case of CE, there is little empirical evidence of knowledge spillovers. Stucki et al. (2023) find regional concentrations of firms active in CE in Switzerland. However, to our knowledge, the role of knowledge spillovers has not been directly tested for CE. To shed light on the importance of regional knowledge spillovers for the development of CE activities in companies, we formulate the following hypothesis:

Hypothesis H1: The more CE knowledge there is in a politically defined region, the more CE innovations a firm will implement.

The role of geographical distance for knowledge spillovers in the CE

As mentioned above, the importance of knowledge interactions for innovation has been extensively discussed and empirically tested. One important aspect that has emerged in this debate is the importance of geographical proximity for the transfer of knowledge and experience. However, the term “regional” is not tied to a specific metric distance and may have different meanings in different national contexts. Absolute distance does matter, however, as research shows.

Several studies argue that there is a negative correlation between geographical distance and (green-) knowledge spillovers, meaning that the probability and frequency of knowledge spillover decreases with increasing distance between entities, such as companies or inventors (Malerba et al., 2013; Murata et al., 2014; Roche et al., 2022; Stucki & Woerter, 2017; van der Wouden & Rigby, 2019; van der Wouden & Youn, 2023). The reasons for these results could be the informal and tacit nature of technological knowledge, which spreads more easily over short distances (Jaffe et al., 1993).

However, the geographic scope should also not be too narrow. If the geographic scope is very narrow, there is a risk that hardly any knowledge is available and consequently no regional knowledge spillover is possible (Glückler et al., 2023). This applies in particular to Switzerland, which in itself already has a very small-scale structure.

So far, there is no evidence on how geographical distance affects knowledge spillovers in the case of CE. Drawing from the insights into the impact of geographical distance on knowledge spillovers, we anticipate the manifestation of an inverted U-shaped relationship, with neither too much geographic restriction (municipal level) nor too much extension (canton level) being ideal for generating knowledge spillovers in the CE. Therefore, we formulate the following hypothesis:

> **Hypothesis H2:** CE knowledge at the district level is more important for the implementation of CE innovations in a focal firm than knowledge at the local or more aggregated cantonal level.

Learning from the best

In this section, we dive deeper into the context of regional knowledge spillover and are interested in the question of whether a leading company in the CE is more valuable than the average number of CE activities that companies pursue in a region. We know from the literature that knowledge spillovers from leaders do flow to so called "followers" (Eeckhout & Jovanovic, 2002). In doing so, they bring new ideas and knowledge to the region, influence other regional actors, and remove institutional, technological, and economic barriers. In this context, Bailey et al. (2018) use the term "anchor tenants." These anchor tenants have a high absorptive capacity, invest in R&D activities and are able to generate knowledge externalities in their region (Agrawal & Cockburn, 2003). They also pioneer the implementation of CE and organize relationships among all other actors (Veyssière et al., 2022). These anchor tenants build bridges with other actors in the region to align them with their ideas for creating new products and services.

Such anchor tenants are considered key components within regional ecosystems to promote sustainable regional competitive advantage (Bailey et al., 2018) and are expected to be relevant to CE ecosystems as well (Aarikka-Stenroos et al., 2020). However, to our knowledge, empirical evidence explaining the role of leaders in a region for the specific case of CE is lacking so far. Therefore, we want to test the following hypothesis:

> **Hypothesis H3:** The CE knowledge of leading companies, so called "anchor tenants", is more important for the implementation of CE innovations in a focal firm than the knowledge of followers.

The role of general innovation knowledge

There is an extensive strand of literature dealing with knowledge spillovers between different industries. These show that knowledge and experience from different industries are relevant for the development of new ideas, products and processes and that so-called inter-industry knowledge spillovers play a crucial role (Malerba et al., 2013; Scherer, 1982; Verspagen, 1997).

Similarly, knowledge from traditional technologies is expected to play a critical role in the development of green innovations (Aghion, Dechezleprêtre, Hemous, et al., 2016). This is especially true because many companies still have little green knowledge and therefore need to build heavily on experience in other areas (Ben Arfi et al., 2018; Stucki & Woerter, 2017, 2022)

By combining the insights from these two strands of literature and applying them to our topic of regional sources of knowledge in the CE, we assume that not only CE-specific knowledge, but also general innovation knowledge, will play a role in stimulation CE innovation activities. However, the role of general innovation knowledge for the CE has hardly been studied so far. An exception is Stucki et al. (2023), who find that general innovation knowledge within a company is relevant for the implementation of the CE. We now assume that not only *internal* general knowledge, but also knowledge available in the region can stimulate CE activities. Specifically, we therefore formulate the following hypothesis:

> **Hypothesis H4:** The more general innovation knowledge there is in a politically defined region, the more CE innovations a company will implement.

Empirical concept

Data

For the empirical analysis, we use unique survey data on CE activities of companies collected in Switzerland in 2020. Switzerland is particularly relevant for this study because, as an innovation-intensive country, it has ideal conditions for a successful transition to a CE and, at the same time, is heavily dependent on such a transition due to its scarce resource deposits. It is therefore likely that the findings from this study can also be transferred to other countries with a time lag.

The survey is based on the KOF Enterprise Panel, a stratified random sample of 8,000 Swiss firms that is representative of the population of firms (industry, region, and size class). For the companies in the sample, the panel includes direct contacts who are familiar with completing such questionnaires and are well informed about general business activities; typically, these are the Chief Executive Officer, Chief Financial Officer or Research & Development department head. Since more than 99% of all companies in Switzerland are small and medium-sized enterprises with fewer than 250 employees, these individuals usually have a good overview of the activities in the company and are therefore well suited to complete the questionnaire. To further ensure the representativeness of the data, an extensive round of reminders for underrepresented industries, regions and size classes was carried out 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 Covid-19 pandemic (for more information on the composition of the sample, see Stucki & Woerter, 2021).

The survey is based on a specially developed concept that distinguishes 27 measures typically relevant to the implementation of the CE at the corporate level. The measures relate to the three fundamental

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strategies of a CE and include activities to (a) increase resource efficiency by using fewer resources per product (Bocken et al., 2016), (b) slow down resource cycles by extending product lifetimes and (c) close resource loops through recycling and reuse (McDonough & Braungart, 2010; Stahel, 1994, 1997). Specifically, the survey asked in which of these 27 measures companies achieved measurable improvements between 2017 and 2019 (see Appendix A.1 for specific survey questions). The 27 measures deal with specific sustainability improvements in processes (e.g. logistics, production, procurement) and products (e.g. design) along the entire value chain of the companies and therefore include both CE process and product innovations. These data allow us to ideally map the CE innovation of the companies and, due to the representativeness of the sample, also to derive conclusions about the existing knowledge in different regions. At the same time, the dataset contains further company and market information, such as the intensity of competition, the qualification level of the employees or the industry affiliation, which typically influence the CE activities of the companies (for more information on the survey, see Stucki et al., 2023).

Methodology

Implementing CE activities is essentially a question of innovation capability; at its core, it is about making products and processes increasingly circular, along the entire value chain, through innovative adaptations. Therefore, we build our regression model on a well-founded innovation model (see, e.g., Cohen, 2010; Crepon et al., 1998). Important factors in such a model are firm size, competition intensity, export activities, financial resources or industry affiliation. Furthermore, in this model it is important to control for specific drivers of the CE such as the strategic embedding of sustainability in the company or energy intensity (see Stucki et al., 2023).

We then add the regional innovation knowledge variables to this comprehensive innovation model. To properly identify the effect of regional knowledge, it is critical that we also control for internal innovation knowledge, i.e., firms' absorptive capacity. We do this by controlling for formal knowledge and R&D activities in our baseline model. Thus, our basic regression equation is defined as follows:

$$CE\ activity = \alpha Innovation\_drivers + \beta CE\_drivers + \gamma Internal\_knowledge + \partial Regional\_knowledge + \varepsilon \quad (1)$$

where ε is an error term and *Regional_knowledge* distinguishes between (a) the *geographical distance* of regional knowledge (hypothesis 2), (b) the *quality* of regional knowledge (hypothesis 3), or (c) *general* or CE-specific regional knowledge (hypothesis 4), depending on the hypothesis being tested. For a detailed description of all covariates, see the summary statistics in Table 1 and the correlation table in Table A.2.

To empirically investigate the interaction between regional knowledge and the implementation of the CE in companies, we estimate a fractional logit model in a first step. The dependent variable in this model is based on a restricted count variable that can take values between 0 and 27, and was transformed into a fractional variable (Papke & Wooldridge, 1996; Wooldridge, 2010). To examine the extent to which the effect of regional knowledge differs in the transition process, we estimated multinomial logit regressions (Cameron & Trivedi, 2005) in which we defined different groups of firms according to the degree of transformation (Stage 0 (baseline): no CE activities (28% of the companies); Stage 1: 1-4 CE activities (38%); Stage 2: 5-9 CE activities (23%); Stage 3: > or equal 10 CE activities (11%)).

With cross-sectional data, it is almost impossible to identify clear causal effects. However, our main variables relate to information on regional knowledge, which is formed independently of the knowledge of the focal firm. Accordingly, we can assume that the regional variables at best influence the activities of the firms, but are hardly influenced by the activities of the firms themselves. Thus, some causality of effects is already implicit in the data. This is less the case for other model variables. For example, a company's financial resources may promote its CE activities, but it may also be the case that its CE activities gave the company more financial flexibility in the first place. Therefore, although the model includes an extensive vector of control variables that significantly reduces the risk of bias from omitted variables, we refrain from making causal statements and interpret our results primarily as partial correlations.

Empirical results

Main results

In Table 2, we test the general effects of regional CE knowledge on the implementation of CE innovations in firms. Column 1 shows the results of the fractional logit regression. As expected in Hypothesis 1, these results indicate that regional CE knowledge does indeed have the expected positive correlation with CE innovation of companies. Thus, firms located in regions with more CE knowledge are on average also more likely to introduce CE innovations. In columns 2 to 4, we then estimated a multinomial model that distinguishes different stages of CE innovation implementation. The results suggest that the effect of regional knowledge is relatively linear; regional knowledge thus supports not only the entry into CE (stage 1), but also the frontier of CE innovation (stage 3).

In Table 2, we examined the effects of regional knowledge at the district level. However, as expected in Hypothesis 2, geographical distance is likely to play an important role in how large the effect of regional knowledge ultimately is. We examine the role of geographical distance in Table 3. In column 1, we summarize knowledge at a very small level by aggregating it at the level of municipalities; there are 2,136 municipalities in Switzerland. In column 2, we do so at the district level, as in Table 2, where the Federal Statistical Office distinguishes 148 districts in Switzerland. In column 3, the aggregation is even broader and is presented specifically for the 26 cantons of Switzerland. As expected in hypothesis 2, knowledge at the district level shows the largest effect. At both the municipality and canton levels, the effect (although positive) is not statistically significant. This result is also confirmed in column 4, where we then simultaneously control for knowledge at the different geographic levels. Not surprisingly, the estimation accuracy decreases somewhat here, since no exclusive categories were formed for the regional knowledge variables (i.e., knowledge at the municipal level is also part of the knowledge at the canton level) and thus the correlation of the three variables is relatively high.

In Table 4, we test the effects of the quality of knowledge. Specifically, we want to test whether there are mainly knowledge spillovers from leading firms, as expected in hypothesis 3, or whether there are also spillovers from the experience of firms with low implementation knowledge. To this end, we divide regional knowledge (at the district level) into three different variables: in column 1, we test the effect of low implementation knowledge (proportion of companies with 1-5 out of 27 CE activities in the region of the focal company excluding the focal company), in column 2 the effect of medium implementation knowledge (proportion of companies with 6-10 CE activities), and in column 3, as in the previous regressions, the effect of high implementation knowledge (proportion of companies with more than 10 CE activities). Finally, in column 4, all three variables are included in the model simultaneously, with the proportion of firms without CE activities serving as the reference category. In line with hypothesis 3, the results indicate that ultimately only frontier knowledge achieves an effect, i.e., companies can only learn from the best. For deep and medium implementation knowledge, the effects are close to zero and clearly not statistically significant.

Finally, to test hypothesis 4, we add a variable to our model that reflects regional knowledge about general innovations (see Table 5). Column 1 suggests that general knowledge also has a positive effect on the implementation of CE innovation at firm-level. However, the effect is somewhat smaller compared to CE-specific knowledge, although the difference is not statistically significant (see column 2).

As for the effects of the other model variables, there were few surprises. Consistent with previous results (e.g., Stucki et al., 2023), we find that, in particular, the availability of financial resources, non-price competition, R&D activities, firm size and strategic embedding of sustainability in the firm are important characteristics of firms with CE activities.

Robustness

To check the robustness of our results, we perform several tests (see Table A3). In principle, it is possible that CE knowledge is most widespread in regions where customers are also more aware of sustainability issues and, accordingly, companies are more willing to adopt CE innovations. In principle, we would expect this awareness to be stronger in cities. To test for such possible omitted variable bias, we therefore include controls for whether a company is located in core municipalities or agglomeration municipalities, respectively, in columns 1 and 2. While the effect for core municipalities is clearly statistically significant, it has only a small effect on the effect of regional knowledge.

In our main regressions, we test the effect of available knowledge in the region of the focal firm. It is possible that these effects reflect not only the influence of knowledge but also certain regional effects (e.g., different political environments). To control for such effects, we add in column 3 fixed effects for the seven major regions of Switzerland which are defined by the Federal Statistical Office. This reduces the effect of regional knowledge somewhat, but it remains statistically significant and positive. The fact that the effect becomes somewhat smaller is not surprising, since we now distinguish primarily regional differences within the major regions, thus strongly limiting the variance in the knowledge variables.

Another potential bias may arise if regional knowledge is tied to specific industry structures, which in turn could affect firms' ability to implement CE innovations. In each of the previous models, we controlled only for sector effects, which can only partially address such a bias. In column 4, we therefore add controls for 34 industry classes. However, this has little effect on the size or significance of the effect of regional knowledge.

Finally, as our variables for regional knowledge are not measured at company level but at a more aggregated level, the shown robust standard errors may be biased. To deal with this issue, we also made regressions with clustered standard errors which allow for intragroup correlation. The results indicate that our results are robust to such clustering (results are available on request).

Discussion

Our study makes a valuable contribution to the existing literature on regional knowledge spillovers, specifically emphasizing the significance of distance and anchor tenants (e.g., Bailey et al., 2018; van der Wouden & Youn, 2023; Veyssière et al., 2022). While prior research, such as that by Malerba et al. (2013), underscores the importance of regional knowledge spillovers for general innovation, our work extends this focus to the realm of CE innovation. Although some studies have explored the impact of regional knowledge on green innovation (Aghion, Dechezleprêtre, Hémous, et al., 2016; Kok et al., 2021; Stucki & Woerter, 2022), the exploration of CE innovation remains relatively scarce. This gap in the literature is particularly crucial because CE innovation is inherently more complicated and multifaceted and has a direct impact on the use of external knowledge. Our findings indicate that both general and CE knowledge within a region significantly influence the implementation of CE innovation and affect both the entry into CE innovation and the technological frontier. However, the nature of regional knowledge proves to be a critical factor.

First, *geographical distance* emerges as a pivotal factor, revealing an inverted U-shaped relationship. Spillover is optimal if the geographical distance is neither too small (at municipal level) nor too large (at cantonal level). While this supports previous studies that emphasize the importance of geographical proximity for knowledge spillovers (Malerba et al., 2013; Murata et al., 2014; Roche et al., 2022; van der Wouden & Youn, 2023), our research introduces a novel insight—an inverted U-shaped relationship—which has not been thoroughly discussed in the knowledge spillover literature. This finding goes beyond the typical focus on urban areas and is in line with studies on innovation in rural areas, which discuss the role of scarcely populated areas for innovation (Glückler et al., 2023).

Secondly, the *quality* of knowledge proves to be crucial, with spillovers emanating primarily from knowledge originating from leading firms. Interestingly, firms find limited benefits from the experiences of new entrants in the CE. This aspect advances the discourse on the significance of anchor tenants for CE innovation, providing comprehensive quantitative data to confirm their importance (Agrawal & Cockburn, 2003). Importantly, our study breaks new ground by addressing this topic with a quantitative approach for the role of anchor tenants for CE, complementing existing theoretical and qualitative data (Aarikka-Stenroos et al., 2020; Veyssière et al., 2022).

Thirdly, not only specific CE knowledge, but also *general* innovation knowledge within a region stimulates a company's CE innovation activities. There is therefore not only a knowledge spillover between regions, but also between technologies. This result is in line with the literature on green innovation, where knowledge spillovers from non-green innovations are also observed (Aghion, Dechezleprêtre, Hémous, et al., 2016; Stucki & Woerter, 2017). This result is of great importance, as most companies have hardly any specific CE knowledge to date. If they can now also draw on general innovation knowledge when transforming to a CE, this will make the transition much easier. However, it must also be clearly emphasized at this point that the effect of CE-specific knowledge is significantly greater, so that companies will not be able to avoid building up specific knowledge in this area.

Conclusion

If we are to achieve our environmental goals, we must massively reduce material consumption, which requires a fundamental shift in our economy to a CE. There is no time to lose in this process, so it is important to use existing knowledge and learn from experience. With this paper, we aim to contribute to a better understanding of how existing regional knowledge leads concretely to new CE innovations and what kind of knowledge is particularly important in this process.

These findings have immediate implications for policy making. It turns out that knowledge transfer can play a central role in the transition to CE. Accordingly, it is important to promote knowledge sharing among firms by building networks. Since geographical distance plays a role, regional networks are particularly important for this. The main focus here is on experience from the leading firms. Public procurement can be used to specifically promote such flagship examples. However, it is also important that these examples are then widely communicated and that corresponding experiences are widely disseminated. The finding that general knowledge also has an effect shows that not completely new networks have to be built up, but that existing innovation networks can be specifically adjusted to the CE in order to strengthen the knowledge spillover and accelerate the transition.

This study is probably the first to comprehensively examine the role of regional knowledge for CE innovation in companies. The results indicate that this is indeed a relevant and interesting area of research. And there is ample room for future studies. Our study is based on cross-sectional data for Switzerland. To test the robustness of the results, it would be desirable to conduct such a study in the future with panel data and also for other countries. This is the only way to identify and understand differences between countries. The focus of our study is on regional knowledge from other companies. However, from the open innovation literature it appears that there are many other relevant sources of knowledge (customers, universities, etc). It would be important to know more precisely how each knowledge source specifically affects the implementation of CE innovation. In this context, further research could also direct the spotlight towards cluster theory (Porter, 1998). The interlinkages, competitive dynamics and geographical proximity between different companies and institutions, combined with the adaptability of infrastructure, support services and institutional backing to the specific needs of companies, could create an environment that favours regional knowledge spillovers for the creation of CE innovations.

In addition to the diffusion of knowledge, various regional factors play a pivotal role in driving the advancement of CE innovations. Notably, a study by Meili and Stucki (2023) suggests that regional household income and public procurement exert positive influences. The question arises as to which other regional factors, such as resource scarcity and supply bottlenecks, act as a catalyst in certain regions and encourage companies to actively engage in the CE.

Beyond these considerations, a crucial aspect involves exploring the effectiveness of policy instruments in fostering CE innovations and identifying where their greatest impact lies. In this context, delving into research on smart regulation becomes imperative. Such investigations can facilitate the collaborative efforts of diverse public and private stakeholders in crafting a well-balanced mix of policy instruments conducive to CE initiatives (Gunningham & Sinclair, 2017).

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List of legends:

Table 1: Descriptive information

Variable	Description	Mean	Std. Dev.	Min	Max
Dependent variable					
CE overall	Share of the 27 circular economy activities adopted	0.16	0.16	0	1
Knowledge variables					
CE know high (district level)	Share of companies with more than 10 CE activities (p90) in the region of the focal company (excluding the focal company)	0.09	0.08	0	1
General know high (district level)	Share of companies with general R&D expenditures of more than CHF 500,000 (p90) in the region of the focal company (excluding the focal company)	0.10	0.09	0	1
Control variables					
CE invest	Intensity in circular economy investments	2.72	1.37	1	6
export	Firm is an exporter, yes/no	0.43	0.50	0	1
foreign owned	Foreign ownership, yes/no	0.14	0.34	0	1
price comp	Intensity of price competition, 5-level ordinate variable	3.95	1.02	1	5
non-price comp	Intensity of non-price competition, 5-level ordinate variable	3.11	1.01	1	5
R&D	R&D activities, yes/no	0.31	0.46	0	1
academ education	Share of employees with academic tertiary-level education	13.95	18.09	0	100
higher education	Share of employees with non-academic tertiary-level education	16.66	15.35	0	100
apprentices	Share of employees with secondary-level education	4.96	6.30	0	68
vocational	Share of employees in vocational training	44.60	23.75	0	100
business-model	Anchoring of sustainability in the business model, transformation of 5-level ordinate variable into binary variable 0 (weak: values 1, 2, 3) and 1 (strong: values 4, 5)	0.15	0.36	0	1
energy int	Energy cost share, in logs	0.91	0.71	0	4.51
age	Firm age, in logs	3.83	0.84	0	6.18
family owned	Firm is family owned, yes/no	0.56	0.50	0	1
company size	Number of employees measured in full-time equivalents, in logs	3.95	1.31	1.61	9.82

Table 2: The effect of regional CE knowledge on CE activities, Fractional logit (column 1) and multinomial logit regressions (columns 2-4; baseline = stage 0)

Stage	CE overall	1	2	3
CE know high (district level)	0.98**	0.47	1.51	1.79+
	(0.40)	(0.91)	(1.06)	(1.22)
CE invest	0.24***	0.52***	0.78***	0.87***
	(0.02)	(0.08)	(0.09)	(0.10)
export	0.06	0.03	0.29+	0.03
	(0.07)	(0.18)	(0.20)	(0.25)
foreign owned	-0.01	0.18	-0.06	0.20
	(0.09)	(0.24)	(0.28)	(0.32)
price comp	0.00	0.11	0.15*	0.12
	(0.04)	(0.08)	(0.09)	(0.12)
non-price comp	0.09***	0.05	0.09	0.27**
	(0.03)	(0.08)	(0.09)	(0.11)
R&D	0.17**	0.37*	0.49**	0.61**
	(0.08)	(0.20)	(0.22)	(0.26)
academ education	0.00	0.01**	0.02**	0.01
	(0.00)	(0.01)	(0.01)	(0.01)
higher education	0.00	-0.00	-0.00	0.00
	(0.00)	(0.01)	(0.01)	(0.01)
apprentices	0.01*	-0.02	0.01	0.02
	(0.00)	(0.01)	(0.01)	(0.02)
vocational	0.00	0.01+	0.01**	0.01+
	(0.00)	(0.00)	(0.00)	(0.01)
business-model	0.51***	0.42+	1.15***	1.70***
	(0.08)	(0.29)	(0.31)	(0.33)
energy int	0.12**	0.04	0.18+	0.28*
	(0.05)	(0.11)	(0.13)	(0.15)
age	0.01	0.02	0.10	0.02
	(0.04)	(0.09)	(0.11)	(0.14)
family owned	0.18***	0.04	0.19	0.30
	(0.07)	(0.16)	(0.19)	(0.23)
company size	0.15***	0.19***	0.37***	0.46***
	(0.03)	(0.07)	(0.08)	(0.10)
constant	-3.97***	-2.45***	-5.88***	-7.76***
	(0.29)	(0.56)	(0.70)	(0.95)
Sector FE	yes	yes	yes	yes
N	1404		1404	
pseudo R2			0.12	
Wald chi2	403.37***		294.32***	
Log Likelihood	-433.37		-1623.78	

Notes: + $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Stage 0: no CE activities; Stage 1: 1-4 CE activities; Stage 2: 5-9 CE activities; Stage 3: >10 CE activities; robust standard errors in parentheses; sector fixed effects: we include fixed effects for construction, modern services, traditional services, and high-tech manufacturing (reference: low-tech manufacturing).

Table 3: Differences by “geographical distance” of regional knowledge, Fractional logit regression

	(1)	(2)	(3)	(4)
		CE overall		
CE know high (municipal level)	0.14			-0.05
	(0.17)			(0.22)
CE know high (district level)		0.98**		1.09+
		(0.40)		(0.70)
CE know high (canton level)			0.34	-0.34
			(0.92)	(1.12)
CE invest	0.24***	0.24***	0.24***	0.24***
	(0.03)	(0.02)	(0.02)	(0.03)
export	0.00	0.06	0.05	0.01
	(0.08)	(0.07)	(0.07)	(0.08)
foreign owned	-0.00	-0.01	-0.00	-0.02
	(0.09)	(0.09)	(0.08)	(0.09)
price comp	0.02	0.00	0.00	0.02
	(0.04)	(0.04)	(0.04)	(0.04)
non-price comp	0.07*	0.09***	0.09***	0.07*
	(0.04)	(0.03)	(0.03)	(0.04)
R&D	0.19**	0.17**	0.17**	0.19**
	(0.08)	(0.08)	(0.08)	(0.08)
academ education	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
higher education	-0.00	0.00	0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)
apprentices	0.01+	0.01*	0.01*	0.01
	(0.01)	(0.00)	(0.00)	(0.01)
vocational	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
business-model	0.50***	0.51***	0.50***	0.51***
	(0.08)	(0.08)	(0.08)	(0.09)
energy int	0.13**	0.12**	0.11**	0.13**
	(0.05)	(0.05)	(0.05)	(0.05)
age	0.01	0.01	0.00	0.01
	(0.05)	(0.04)	(0.04)	(0.05)
family owned	0.19**	0.18***	0.18***	0.18**
	(0.07)	(0.07)	(0.07)	(0.07)
company size	0.17***	0.15***	0.16***	0.17***
	(0.03)	(0.03)	(0.03)	(0.03)
constant	-3.98***	-3.97***	-3.92***	-4.01***
	(0.32)	(0.29)	(0.30)	(0.33)
Sector FE	yes	yes	yes	yes
N	1210	1404	1411	1210
Wald chi2	336.51***	403.37***	387.06***	350.07***
Log Likelihood	-374.79	-433.37	-436.64	-374.40

Notes: + $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; robust standard errors in parentheses; sector fixed effects: we include fixed effects for construction, modern services, traditional services, and high-tech manufacturing (reference: low-tech manufacturing).

Table 4: Differences by "quality" of regional knowledge, Fractional logit regression

	(1)	(2)	(3)	(4)
	CE overall			
CE know low (district level)	0.02			0.28
	(0.24)			(0.25)
CE know medium (district level)		-0.03		0.21
		(0.22)		(0.26)
CE know high (district level)			0.98**	1.15***
			(0.40)	(0.43)
CE invest	0.24***	0.24***	0.24***	0.24***
	(0.02)	(0.02)	(0.02)	(0.02)
export	0.05	0.05	0.06	0.06
	(0.07)	(0.07)	(0.07)	(0.07)
foreign owned	-0.00	-0.00	-0.01	-0.01
	(0.09)	(0.09)	(0.09)	(0.09)
price comp	0.01	0.01	0.00	0.00
	(0.04)	(0.04)	(0.04)	(0.04)
non-price comp	0.09***	0.09***	0.09***	0.09***
	(0.03)	(0.03)	(0.03)	(0.03)
R&D	0.17**	0.17**	0.17**	0.17**
	(0.08)	(0.08)	(0.08)	(0.08)
academ education	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
higher education	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
apprentices	0.01*	0.01*	0.01*	0.01*
	(0.00)	(0.00)	(0.00)	(0.00)
vocational	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
business-model	0.51***	0.51***	0.51***	0.50***
	(0.08)	(0.08)	(0.08)	(0.08)
energy int	0.12**	0.12**	0.12**	0.12**
	(0.05)	(0.05)	(0.05)	(0.05)
age	0.00	0.00	0.01	0.01
	(0.04)	(0.04)	(0.04)	(0.04)
family owned	0.18***	0.18***	0.18***	0.18***
	(0.07)	(0.07)	(0.07)	(0.07)
company size	0.16***	0.16***	0.15***	0.15***
	(0.03)	(0.03)	(0.03)	(0.03)
constant	-3.90***	-3.89***	-3.97***	-4.13***
	(0.32)	(0.29)	(0.29)	(0.32)
Sector FE	yes	yes	yes	yes
N	1404	1404	1404	1404
Wald chi2	386.82***	387.16***	403.37***	404.75***
Log Likelihood	-433.93	-433.93	-433.37	-433.27

Notes: + $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; robust standard errors in parentheses; sector fixed effects: we include fixed effects for construction, modern services, traditional services, and high-tech manufacturing (reference: low-tech manufacturing).

Table 5: The role of general regional knowledge, Fractional logit regression

	(1)	(2)
	CE overall	
General know high (district level)	0.54*	0.49+
	(0.28)	(0.31)
CE know high (district level)		0.90**
		(0.41)
CE invest	0.24***	0.24***
	(0.02)	(0.02)
export	0.04	0.05
	(0.07)	(0.07)
foreign owned	0.01	0.00
	(0.09)	(0.09)
price comp	0.00	0.00
	(0.04)	(0.04)
non-price comp	0.09***	0.09***
	(0.03)	(0.03)
R&D	0.18**	0.19**
	(0.08)	(0.08)
academ education	0.00	0.00
	(0.00)	(0.00)
higher education	0.00	0.00
	(0.00)	(0.00)
apprentices	0.01**	0.01*
	(0.00)	(0.00)
vocational	0.00	0.00
	(0.00)	(0.00)
business-model	0.50***	0.50***
	(0.08)	(0.08)
energy int	0.12**	0.12**
	(0.05)	(0.05)
age	0.01	0.01
	(0.05)	(0.05)
family owned	0.18***	0.18***
	(0.07)	(0.07)
company size	0.16***	0.16***
	(0.03)	(0.03)
constant	-3.99***	-4.07***
	(0.30)	(0.30)
Sector FE	yes	yes
N	1382	1380
Wald chi2	383.67***	396.21***
Log Likelihood	-426.81	-424.77

Notes: + $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; robust standard errors in parentheses; sector fixed effects: we include fixed effects for construction, modern services, traditional services, and high-tech manufacturing (reference: low-tech manufacturing).

Table A.1: Survey Questions

Notes: 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

Table A.2: Correlation table

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	CE overall	1.00																
2	CE invest	0.37	1.00															
3	export	0.09	0.09	1.00														
4	foreign owned	0.02	0.04	0.19	1.00													
5	price comp	0.07	0.04	0.01	0.04	1.00												
6	non-price comp	0.10	0.06	0.11	0.01	0.26	1.00											
7	R&D	0.17	0.16	0.40	0.03	0.02	0.11	1.00										
8	academ education	-0.05	-0.04	0.18	0.11	-0.12	0.05	0.15	1.00									
9	higher education	-0.03	0.00	0.05	0.10	-0.04	0.03	0.04	0.13	1.00								
10	apprentices	0.04	-0.02	-0.16	-0.12	0.15	-0.02	-0.07	-0.14	-0.09	1.00							
11	vocational	0.03	-0.03	-0.12	-0.08	0.00	-0.03	-0.12	-0.47	-0.37	0.07	1.00						
12	business-model	0.27	0.28	0.03	0.00	0.05	0.00	0.12	0.06	0.05	-0.01	-0.04	1.00					
13	energy int	0.10	0.15	-0.05	-0.07	-0.05	-0.04	0.00	-0.15	-0.10	-0.04	0.02	0.00	1.00				
14	age	0.10	0.11	0.07	-0.04	0.13	-0.01	0.03	-0.15	-0.03	0.13	0.10	-0.02	0.02	1.00			
15	family owned	0.07	0.04	-0.01	-0.14	0.19	0.03	0.00	-0.26	-0.13	0.08	0.10	-0.03	0.08	0.10	1.00		
16	company size	0.24	0.16	0.18	0.14	0.09	0.05	0.17	-0.02	-0.03	0.00	0.02	0.10	-0.03	0.28	-0.12	1.00	
17	CE know high (district level)	0.05	-0.04	-0.03	0.04	0.02	0.02	-0.01	0.04	0.04	0.02	0.01	0.00	-0.04	-0.03	-0.01	0.03	1.00
18	General know high (district level)	0.05	-0.01	0.05	0.00	0.00	0.00	0.03	-0.02	0.02	0.03	0.08	0.05	-0.09	0.03	0.01	0.01	0.14

Table A.3: Including additional controls, Fractional logit regressions

	(1)	(2)	(3)	(4)
	CE overall			
CE know high (district level)	0.95**	0.95**	0.75*	0.97**
	(0.40)	(0.40)	(0.43)	(0.40)
CE invest	0.24***	0.24***	0.25***	0.24***
	(0.02)	(0.02)	(0.02)	(0.02)
export	0.04	0.05	0.07	0.04
	(0.07)	(0.07)	(0.07)	(0.08)
foreign owned	-0.02	-0.02	-0.01	0.00
	(0.09)	(0.09)	(0.08)	(0.09)
price comp	-0.00	-0.00	0.00	-0.01
	(0.04)	(0.04)	(0.04)	(0.04)
non-price comp	0.09***	0.09***	0.09***	0.07**
	(0.03)	(0.03)	(0.03)	(0.03)
R&D	0.17**	0.17**	0.16**	0.17**
	(0.08)	(0.08)	(0.08)	(0.08)
academ education	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
higher education	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
apprentices	0.01*	0.01*	0.01+	0.01*
	(0.00)	(0.00)	(0.00)	(0.01)
vocational	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
business-model	0.51***	0.50***	0.50***	0.53***
	(0.08)	(0.08)	(0.08)	(0.08)
energy int	0.11**	0.11**	0.13***	0.14***
	(0.05)	(0.05)	(0.05)	(0.05)
age	0.01	0.01	-0.00	0.02
	(0.04)	(0.04)	(0.04)	(0.05)
family owned	0.17**	0.17**	0.17**	0.15**
	(0.07)	(0.07)	(0.07)	(0.07)
company size	0.16***	0.16***	0.15***	0.16***
	(0.03)	(0.03)	(0.03)	(0.03)
core municipality	-0.15**	-0.14*		
	(0.07)	(0.08)		
agglomeration		0.02		
		(0.07)		
constant	-3.92***	-3.93***	-4.04***	-4.30***
	(0.29)	(0.29)	(0.29)	(0.46)
Sector FE	yes	yes	yes	yes
Industry FE	no	no	no	yes
Region FE	no	no	yes	no
N	1404	1404	1404	1404
Wald chi2	411.86***	414.51***	426.49***	528.97***
Log Likelihood	-433.01	-433.00	-432.66	-430.06

Notes: + $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust Standard errors in parentheses; Sector fixed effects: we include fixed effects for construction, modern services, traditional services, and high-tech manufacturing (reference: low-tech manufacturing).