Circular economy innovations, growth and employment at the firm level
Empirical evidence from Germany

Jens Horbach1 | Christian Rammer2

1 Augsburg University of Applied Sciences, Augsburg, Germany
2 Centre for European Economic Research, Mannheim, Germany

Correspondence
Jens Horbach, Augsburg University of Applied Sciences, An der Hochschule 1, 86161 Augsburg, Germany.
Email: jens.horbach@hs-augsburg.de

Editor Managing Review: Junming Zhu

Abstract
Circular economy (CE) describes a concept that aims at saving resources by minimizing the use of material and energy over the entire life-cycle of products, including production and repair, as well as reuse and recycling. CE innovations help to realize the goals of sustainable development by targeting environmental, economic, and social dimensions of sustainability. This paper looks at the economic and social dimensions by investigating whether firms with CE innovations perform better or worse in terms of sales growth and employment. Our econometric analysis uses data from two waves of the German part of the Community Innovation Survey. Quantile regressions show that CE innovations are positively linked to turnover and employment growth. While there is no statistically significant impact on labor productivity, at the same time, firms with CE innovations show a significantly better financial standing.

KEYWORDS circular economy, community innovation survey, eco-innovation, growth, industrial ecology, quantile regression

1 INTRODUCTION

Circular economy (CE) describes a regenerative system in which material input, waste, emissions, and energy use are minimized over the entire life-time of products (Geissdoerfer, Savaget, Bocken, & Hultink, 2017; Korhonen, Honkasalo, & Seppälä, 2018). This can be achieved by reducing material and energy input per unit of output during production, by designing products in a way that increases their life-time, or by the repair, reuse, and recycling of products. The CE approach is a key element in greening the economy and is therefore in the center of the sustainability policy debate (Millar, McLaughlin, & Börger, 2019). Some authors claim that the CE helps realizing all three dimensions of a sustainable development by addressing environmental, economic, and social aspects (e.g., Korhonen et al., 2018; Schroeder, Anggraeni, & Weber, 2018).

The CE approach has also attracted the attention of many firms. On the one hand, it can make production processes more efficient, which is particularly important when material and energy inputs become more expensive. On the other hand, CE innovations can be a component in the wider attempt of firms toward corporate social responsibility and sustainability efforts (Reif & Rexhäuser, 2018). While environmental impacts of CE have been widely studied (see, e.g., Domenech & Bahn-Walkowiak, 2019), rather little is known about the link between CE activities and firm growth and employment, which is supposed to represent the economic and social dimensions of sustainable development. While the purpose of CE is certainly not to spur growth of firms, it is important to know for the sake of policy making whether firms that invest in CE activities will benefit or suffer in terms of their growth prospects and labor demand.

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The aim of this paper is to look at this link empirically and analyze whether firms that engage in CE innovations experience positive or negative results in terms of sales growth and employment. As both can be achieved in the short run, albeit at the expense of economic performance, we also investigate the link between CE innovation, and a firm’s financial standing and its productivity.

To do so, we exploit data from the German part of the Community Innovation Survey (CIS) 2014. This survey contains a module on innovations with environmental benefits, which allows us to identify CE innovation at the firm level. We investigate whether firms with CE innovations during a 3-year period (2012–2014) show higher or lower growth in sales, employment or productivity in the subsequent period (2014–2016), and higher or lower financial performance in 2016. We employ quantile regressions in order to determine whether this link is different for firms with different growth performance.

2 | DEFINITION AND SCOPE OF THE CE

The CE is a very broad and heterogeneous concept covering activities such as product-life extension, reuse, repair and recycling, material and energy efficiency, and new modes of socio-technical organization. De Jesus and Mendonça (2018, p. 76) consider CE “as a multidimensional, dynamic, integrative approach, promoting a reformed socio-technical template for carrying out economic development, in an environmentally sustainable way, by rematching, rebalancing, and rewiring industrial processes and consumption habits into a new usage-production closed-loop system.” There are numerous ways of defining CE. Kirchherr, Reike, and Hekkert (2017) identified 114 different definitions of the CE concept in the literature. In this paper, we essentially follow Geisdoerfer et al. (2017, p. 759), who define CE as “a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops,” stressing the role of repair, reuse, remanufacturing, refurbishing, and long-lasting design in achieving this system. In addition, we build upon the work of Korhonen et al. (2018), who stress the role of cyclical materials flows and renewable energy sources for arriving at a circular economy. They also highlight that CE covers all three dimensions of sustainable development. A circular economy thus also includes the social dimension such as the link of CE innovation to employment.

The focus of the present paper is on the firm perspective of CE. Firms are important actors for the realization of a CE. Following the framework of Mihelcic et al. (2003), firms’ activities largely determine the optimization of the “inner circles” of the CE which relate to reducing material and energy consumption, increasing recycling and reuse, and expanding product lifetime. We hence focus, in our analysis, on the activities of firms to adapt their processes and products in that respect. From a firm perspective, these adaptations are often innovations, as they require new or significantly improved production methods or new or substantially redesigned products. CE innovation activities are therefore linked to the concept of eco-innovation (Kemp, 2010). Eco-innovation, however, covers a broader set of activities aiming at reducing the environmental impact of firms, including end-of-pipe technologies to reduce air pollution or noise emissions (see Horbach, Rammer, & Rennings, 2012).

3 | TRANSMISSION CHANNELS FROM CE TO FIRM GROWTH AND EMPLOYMENT

The aim of this paper is to analyze the link between firm growth and employment, and CE innovations. The key research question is whether firms that adopt a CE approach experience higher or lower growth, and whether CE innovations are related to the social dimension of sustainability. We start with the link between CE and growth and then move to employment.

From a theoretical perspective, there are three main transmission channels from CE to firm growth. First, CE innovation activities such as the reduction of energy and material consumption, the substitution of fossil energy by renewables or the recycling of waste, water or material may lead to cost savings, at least in the long run. These cost savings allow the firm to lower product prices, which can lead to an increased demand for the firm’s products. Nevertheless, in the short run, the introduction of CE innovations may lead to higher costs because additional equipment or organizational changes are required. Such a u-shaped performance effect over time has been found by Soltmann, Stucki, and Wörter (2015).

Second, in the light of the Porter hypothesis (Porter & van der Linde, 1995), new products serving a CE (such as energy saving products or products characterized by a better recyclability or a longer life-time) may lead to first mover advantages that are accompanied by a higher competitiveness of the innovating firm. Third, this effect may be re-enforced if consumers are willing to pay more for the added ecological value of CE improved products or products produced following a CE approach, which has a positive effect on product demand as well. Often firms signal these product characteristics through certificates or eco-labels (see, e.g., Brécard, Boubaker, Sterenn, Perraudeau, & Salladarré, 2009). This argument is also discussed in the Corporate Social Responsibility (CSR) literature (see, e.g., Ambec & Lanoie, 2008; Hart, 1997; Margolis & Walsh, 2003; Orlitzky, Siegel, & Waldman, 2011). “This literature associates the positive returns of greener production choices to improvements in market’s evaluation of the firm, access to new markets or cost reduction driven by increased resource efficiency” (Ghisetti, 2018, p. 59). Especially in regions characterized by a high awareness for green issues, CE innovations might also increase the reputation of a firm, leading to additional positive demand effects (see Horbach & Rammer, 2018).
While there are arguments for positive turnover effects of CE innovations, the link to employment remains undetermined from a theoretical point of view, particularly since employment effects may vary by the type of CE activity. Process-related CE innovations might result in a lower demand for labor if labor productivity increases (see also Horbach & Rennings, 2013). Adopting processes to meet CE goals often requires a redesign of the whole production process, from the choice of materials to the final design of products. Such a modernization might also lead to a substitution of labor by capital (e.g., an increased use of automatization) and a subsequent increase in labor productivity. However, an augmented efficiency of capital may lead to a higher valuation of capital versus labor, thus inducing lower wages, which in turn may alleviate the negative employment effects. Process-related CE activities may also induce a direct increase in labor demand if they require additional investment or more specialized and better qualified employees. There may also be positive employment effects from process-related CE innovations if productivity increases lead to higher price competitiveness and hence higher demand for the innovator’s products (see Aldieri & Vinci, 2018; Van Roy, Vértesy, & Vivarelli, 2018 on the general employment effects associated with the diffusion of new technology).

For product-related CE innovations, employment impacts also remain unclear from a theoretical point of view (see Harrison, Jaumandreu, Mairesse, & Peters, 2014). Entire new CE-related products may induce new demand for the firm, resulting in higher demand for labor in order to expand production of the new product. But an increase of net employment would only emerge if the new product did not substitute a more labor-intensive old product from the firm. The increase of the lifetime of products may lead to lower labor demand via lower annual sales volumes, though this may be compensated by a higher demand for such products. On the macroeconomic level, which is not the focus of this analysis, the employment effects of CE innovations are also not determined, and depend inter alia on the labor intensity of the substituted products. All in all, employment effects of CE remain an empirical issue, as they are undetermined from a theoretical point of view.

Based on these theoretical considerations, we formulate two hypotheses:

**H1:** Lower production costs induced by CE innovations are positively linked to the competitiveness of firms and firms’ sales growth without harming the firms’ financial standing.

**H2:** CE innovations and employment are positively linked because higher competitiveness dominates over an increase in labor productivity and the substitution of more labor-intensive products within firms.

### 4 | EXISTING EMPIRICAL EVIDENCE

There is an extensive literature on the relation of eco-innovations to the general growth and performance of firms (for a recent overview see Ghisetti, 2018). Concerning the special case of CE innovations, there is only very rare evidence at the firm-level, however, which mainly relates to productivity and profitability impacts of CE. A study of Flachenecker and Kornejew (2019) based on cross-country firm-level data from the CIS 2008 finds evidence “for a positive and causal effect of material productivity improvements on microeconomic competitiveness for those firms that received targeted public financial support” (Flachenecker & Kornejew, 2019, p. 87). Nevertheless, the authors show that the positive effects are limited to certain sectors and countries. In a further recent CE-oriented analysis of resource efficiency measures and performance, Horbach (2018) finds that an increased use of renewables leads to a higher performance, whereas measures to reduce water consumption are negatively correlated with turnover development.

Other studies looked at profitability impacts. Ghisetti and Rennings (2014), using the German CIS 2008, find that measures leading to a reduction in the use of energy or material per unit of output lead to higher profit margins, whereas more end-of-pipe oriented measures reduce rather firms’ profitability. Rexhäuser and Rammer (2014) employ the same database and analyze the profitability effects of different types of environmental innovations, including CE-related ones. The authors find “that innovations which do not improve firms’ resource efficiency do not provide positive returns to profitability. However, innovations that increase a firm’s resource efficiency in terms of material or energy consumption per unit of output have positive impacts on profitability” (Rexhäuser & Rammer, 2014, p. 145). Antonietti and Marzucchi (2014) arrive at a similar result for a sample of Italian manufacturing firms with respect to productivity. Investment that reduced raw material input led to positive productivity effects, though only for firms with a medium to high productivity level.

While there are several studies analyzing the employment impacts of CE at the macroeconomic level (see Horbach, Rennings, & Sommerfeld, 2015 for an overview), the empirical literature on firm-level employment effects is quite limited. Early studies find positive effects of eco-innovations (including CE-related ones) on employment (Bijman & Nijkamp, 1988; Pfeiffer & Rennings, 2001; Rennings & Zwick, 2002). These effects tend to differ by the type of eco-innovation, with stronger effects often found for innovations related to CE approaches. Pfeiffer and Rennings (2001) show that cleaner production is more likely to increase employment compared to end-of-pipe technologies. Horbach (2010) finds a positive and significant influence of eco-product innovations on employment. The positive effect of eco-innovation appears to be greater compared to innovations not related to environmental goals. The results of Gagliardi, Marin, and Mirelli (2016), who identified eco-innovations based on patents, confirm these findings. Contrary to this result, Licht and Peters (2014), using German CIS data, find that both environmental and non-environmental product innovations trigger employment growth, but that non-environmental product innovations are more likely to increase
employment. Horbach and Rennings (2013) report higher employment effects in technology fields closely related to CE, such as recycling, and energy and resource efficiency, while end-of-pipe technologies have a negative impact on employment.

Kunapataraawong and Martínez-Ros (2016) point to different employment effects by type of industry. The authors find stronger effects for firms in “dirty” industries. Burger, Stavropoulos, Ramkumar, Dufourmont, and van Oortd (2019) stress the heterogeneity of the skill demand of CE activities. Core CE activities that focus on renewable energy, repair, reuse of materials and the sharing economy generally require more manual and technological skills, whereas enabling activities (management, design, and ICT applicability of CE) require more complex cognitive skills.

Our paper aims to extend the existing literature in three respects: first, we investigate the link between CE and firm growth, which has not been looked at in the literature based on a representative sample of firms across a wide range of sectors; second, we analyze whether higher sales and employment growth emerges at the cost of worsened productivity or financial performance; finally, we want to enlarge our knowledge about likely heterogeneity of the link between CE and growth across slowly and rapidly growing firms, as well as across firm size and sector.

5 | EMPIRICAL APPROACH, DATA, AND DEFINITION OF VARIABLES

For testing our hypotheses, we apply a basic empirical model with firm growth (sales, employment) and firm performance (financial standing, productivity) in the years after a firm engaged in new or extended CE activities as dependent variables. When analyzing the link between CE innovation, growth, and performance, endogeneity issues might emerge. Firms with higher growth and better performance will find it easier to invest in CE activities. In this paper, we attempt to limit endogeneity by strictly linking past CE innovation to later growth and performance, and by considering a number of other determinants of growth and performance in order to avoid an omitted variable bias. Equation (1) shows the basic design of our empirical model, with y representing the growth and performance variables, CE is the CE innovation variable, X is a vector of growth determinants, a is a constant, β1 and β2 are coefficients to be estimated and ε the error term. The index z represents the period after the introduction of CE (t).

\[ y_{it} = \alpha + \beta_1 CE_{it} + \beta_2 X_{it} + \epsilon_i \] (1)

We believe that there is no simultaneity problem causing endogeneity. We acknowledge that firms deciding at the beginning of period t about CE innovation may take expected future growth and performance in period z into account. But these expectations will rest on the determinants of growth and performance that are observable to the firms at time t (X). We also include growth and performance impacts that result from strategic decisions a firm has made during t, such as mergers and acquisitions, outsourcing, sale of firm parts, or establishing new subsidiaries. By including all these variables in vector X, we are confident of capturing the most relevant observable growth determinants, allowing us to assume that no major unobserved confounding variables exist.

Owing to the time structure of our data, reverse causality (i.e., future growth and performance affect past decisions to introduce CE innovation) is very unlikely to occur. As we control for observable growth and performance determinants, it would only be the unexpected part of growth and performance that could drive prior CE innovation. Given the long lag between the time a firm can observe growth and performance (after the end of period z) and the time it made its decision about CE innovation (at the beginning of period t), which is more than 4 years in our data, we assume that simultaneity is not an issue in our study. But as we cannot prove the correctness of our assumptions, we are cautious throughout the paper to interpret the link between past CE innovation and later growth and performance as causal, instead rather viewing it as a correlation.

For estimating the model, we use firm-level panel data of two waves (2014 and 2016) of the German part of the CIS. The 2014 wave contains a special module on innovations (during 2012 and 2014) that led to a reduction of the environmental impact of firm activities. This module allows us to identify CE innovations related both to production processes and products. The 2016 wave supplies the growth and performance variables. The German CIS follows the methodological standards of all CIS which have been developed and are supervised by the Statistical Office of the European Commission. It is based on a stratified random sample, using eight size classes, 56 sectors (both manufacturing and services) and two regions as stratification criteria. The survey is voluntary, and the response rate is between 25% and 30%. A comprehensive non-response survey is used to correct for a potential response bias. The survey form, which is available as paper and online versions, is usually completed by CEOs or innovation managers. For more information on the German CIS, see Peters and Rammer (2013) and Behrens et al. (2017).

CE innovations are defined as follows (a detailed description of all variables and a correlation matrix are included in the supporting information, see Tables S1 and S3 in the Supporting Information): process-related activities, including any new or improved production activity that led to a significant reduction of environmental impacts in terms of energy and material savings per unit of output; the substitution of fossil energy sources by renewables; the substitution of dangerous substances; or a higher recycling rate of waste, water or material within the firm. With respect to
TABLE 1 Share of firms by different types of CE innovations

| CE innovations                                      | Share of firms with significant* CE innovations (%) |
|-----------------------------------------------------|-----------------------------------------------------|
| Process-related CE innovation                       |                                                     |
| Reduced energy use per unit of output               | 10.6                                                |
| Recycled waste, water, or materials for own use or sale | 6.4                                                |
| Reduced material use/use of water per unit of output | 4.8                                                |
| Replaced fossil energy sources by renewable energy sources | 4.0                                                |
| Replaced materials by less hazardous substitutes     | 2.9                                                |
| Product-related CE innovation                       |                                                     |
| Reduced energy use                                  | 7.3                                                |
| Extended product life through longer-lasting/more durable products | 3.7                                                |
| Improved recycling of product after use             | 3.2                                                |
| Any CE innovation                                   | 27.0                                               |

*Firms reporting that the CE innovation had a significant positive impact on the environment.

Source: German CIS 2014, weighted results.

products, CE innovations include the introduction of new or improved products with reduced energy use, improved recyclability, or increased lifetime. Importantly, CE innovations had to differ from previous activities of the firm, which implies that our CE measure does not capture the achieved level of CE in a firm (which could result from activities long ago) but investment in new activities, which is important when looking at links to growth because one may expect a direct link to growth only from new activities. This is also important from a policy perspective, as policy usually wants to incentivize firms to enter into or increase their CE-related activities.

Table 1 shows the share of firms with CE innovations. 27% of all firms in Germany report CE innovations during 2012–2014. The single most important activity is the reduction of energy use per unit of output. Process-related innovations are more frequent than product-related ones.

Growth is measured by the change in sales (Turnover1416) and employment (Emp1416) in the 3-year period after the CE innovation (2014–2016). The firm-level data on sales and employment are taken from the 2016 survey wave and also serves for our productivity measure (sales per employee). Both growth variables are measured against the average growth in a firm’s two-digit industry (using data from the business register) in order to take systematic growth differences between sectors (e.g., owing to different demand dynamics) into account. Data on the firms’ financial standing in the year 2016 are provided by Creditreform, the largest credit rating agency in Germany. The index runs from 100 (best) to 600 (worst) (see Czarnitzki & Kraft, 2007 for more details on this measure). The change of productivity (Labprod1416) is measured by the growth rate of the sales per employee from 2014 to 2016.

Growth determinants include size, age, sector, location, ownership (family vs. non-family firm), export orientation, and the competitive environment (number of competitors, intensity of price competition, and competition from abroad). Size represents the number of employees of the firm, West gets the value one if the firm is located in Western Germany. The variable Export captures firms selling to customers abroad. Family denotes firms that are owned (at least 50% of firm shares) by a family. This variable is considered because family-owned firms might be less focused on their shareholder value. The competitive situation is indicated by the variables Compabroad (measuring the relevance of competition by firms from outside the home country), Pricecomp (measuring whether price increase leads to an immediate loss of customers) and Competitors (measuring the number of competitors in a firm’s main product market).

We also take into account major changes in the firm’s organization during 2012 and 2014 resulting from mergers and acquisition (Event1) and the sale of parts of the firm (Event2) as well as from outsourcing of activities (Event3) and the foundation of new subsidiaries (Event4). All these events can be major drivers of growth. The employment model also includes the change in a firm’s wage level prior to the analyzed period (change in average wages and salaries per employee between 2013 and 2014: Wage1314).

In addition, we control for the general innovative capacity of the firm since we want to isolate changes in growth that are linked to CE activities from other innovation-related growth sources in a firm. The share of graduated employees in 2013 (Highqual) captures positive competitiveness and hence growth impulses from a better qualified workforce. The introduction of product and process innovations during 2012–2014 (Productinno, Processinno) measures growth advantages from a general modernization of a firm’s process technologies and product portfolio. The regional stock of knowledge can serve as another growth source by generating knowledge spillovers. It is measured by the number of patents in the firm’s NUTS 3 region in the years 2008–2012 (Patreg0812) based on data from the Patstat database of the European Patent Office.

4 The figures are weighted to represent the total population of firms in Germany. Item non-response to the question on CE innovations was 6.0% and was corrected for through imputation methods.
6 | ESTIMATION STRATEGY AND RESULTS

Besides OLS estimations as baselines, we also use quantile regressions (see Koenker, 2005) for estimating our four dependent variables. Quantile regressions are advantageous because they allow analyzing the different role of CE innovations for shrinking, stable, slowly growing, or fast growing firms. Furthermore, this estimation method is more robust against outliers and there are no assumptions about the parametric distribution of the error term (see Koenker, 2005). In fact, the growth variables especially show many outliers. Besides a median regression where the objective is an estimation of the median of the dependent variable, conditional on the values of the independent variables, we also estimate regressions for the 25% and 75% quantile.

The $q$th ($0 < q < 1$) quantile regression estimator minimizes the objective function over $\beta_q$ (see Cameron & Trivedi, 2009, p. 207; Koenker, 2005):

$$Q(\beta_q) = \sum_{i:y_i \leq \beta_q} q | y_i - x'_i \beta_q | + \sum_{i:y_i > \beta_q} (1 - q) | y_i - x'_i \beta_q |$$

(2)

$\beta_q$ instead of $\beta$ is used, showing that different choices of $q$ lead to different values of $\beta$. As the objective function is not differentiable, the simplex method is used for a solution. We use the quantile regression method to estimate different quantiles $q$ of the functions for turnover development ($\text{Turnover1416} = f(\text{CE innovation}_{2012-2014}, \text{control variables})$), labor demand ($\text{Emp1416} = f(\text{CE innovation}_{2012-2014}, \text{control variables})$), the financial standing in 2016 ($\text{Finstanding} = f(\text{CE innovation}_{2012-2014}, \text{control variables})$), and labor productivity growth ($\text{Labprod1416} = f(\text{CE innovation}_{2012-2014}, \text{control variables})$).

The results for turnover growth from 2014 to 2016 (Table 2) in relation to turnover growth of the firm’s sector confirm hypothesis H1. The CE innovation variable shows a positive and significant coefficient for the 25% quantile and the median (see Table 2). Process innovators (Processinn) perform better while a high competitive pressure (Compabroad) is associated with a lower turnover growth. Not surprisingly, the sale or closure of parts of the firm (Event2) is negatively correlated to turnover growth and financial standing (see Table 2).
Circular economy innovations and financial standing in German firms (results of OLS and quantile regressions)

Industry dummies are included but not reported. **, *, denote significance at the 10%, 5% and 1% level, respectively.

Table 3, whereas the foundation of subsidiaries (Event4) seems to improve the financial standing of a firm. Family-owned firms are characterized by lower sales growth. This result also holds for the shareholder value. The shareholder value seems to be less important for these firms.

The econometric analysis of the financial standing (Table 3) shows that firms having realized CE innovations from 2012 to 2014 are characterized by a significantly better financial standing in 2016. This is especially relevant for high-performing firms as the coefficient for CE innovation attains its highest value for the 75% quantile (6.79). The result strongly supports hypothesis H1. The regional innovative capacity (Patreg0812) is also relevant for the financial standing of a firm via positive regional spillovers, but this result is only valid for the 25% quantile. Firms with high turnover growth from 2014 to 2016 show a slightly better financial standing in 2016. This result also holds for exporting firms, especially for low (coefficient 7.14) and medium (7.52) growing firms.

A positive link with CE innovations can also be found for the employment indicator. CE innovative firms show a higher growth in employment than firms with strong growth in employment (75% quantile). The positive employment link of CE innovations seems to dominate over a likely reduction in labor demand resulting from higher labor productivity. Estimations of a labor productivity function do not show a significant link between CE innovations and labor productivity growth (see Table 4).

Not surprisingly, employment growth is also triggered by past growth in product demand (Turnover14–16d), whereas a high price competition leads to lower employment growth. The international orientation of a firm is statistically significant for a firm’s employment growth only for the 25% quantile. The so-called Gibrat’s law—which states that employment growth is independent of the initial size of the firm (see Gibrat, 1931)—is confirmed for the median and 75% quantities but not for the 25% quantile.

At first glance, the positive effect of past wage dynamics (Wage1314) on employment growth seems to be counter-intuitive. However, the increasing shortage in qualified labor in Germany forces firms, especially rapidly growing ones, to pay higher wages in order to meet their labor demand. In the light of the efficiency wage theory, only firms that are able to raise wages can attract and retain the required qualified personnel. Rising wages are thus a precondition for an expansion of employment in a situation of labor scarcity. As expected, the sale or closure of parts of the firm (Event2) or outsourcing of firm activities (Event3) evokes a decline in employment.

| Regressors | Dependent variable: Finstanding |
|-----------|--------------------------------|
| CE innovation (2012–14) | OLS 25% quantile Median 75% quantile |
| Processinn (2012–14) | 6.00 (3.51)** 4.63 (1.69)* 5.13 (3.00)** 6.79 (4.74)** |
| Productinn (2012–14) | −0.83 (−0.47) −0.82 (−0.32) −1.08 (−0.77) −0.19 (−0.11) |
| Patreg0812 | 0.04 (1.86)* 0.07 (2.00)* 0.03 (1.39) 0.03 (1.17) |
| Turnov14–16d | 6.18 (4.06)** 3.95 (1.63)* 0.05 (0.03) 2.13 (1.50) |
| Export (2014) | 5.13 (2.68)** 7.14 (2.61)** 7.52 (4.38)** 4.84 (2.47)** |
| Highqual (2013) | −15.3 (−3.50)** −16.3 (−2.93)** −15.5 (−5.93)** −14.5 (−4.59)** |
| Family (2014) | −7.53 (−3.97)** −9.30 (−3.33)** −5.39 (−3.92)** −6.30 (−3.78)** |
| Compabroad (2014) | −0.50 (−0.28) −4.20 (−1.65)* 0.43 (0.28) 1.03 (0.60) |
| Competitors (2014) | −5.57 (−2.93)** −6.57 (−2.58)** −4.04 (−2.70)** −3.40 (−2.08)* |
| Size (2012) | 1.01 (3.79)** 0.56 (4.22)** 0.55 (5.18)** 4.24 (3.54)** |
| West (2014) | −0.36 (−0.10) −4.71 (−0.95) −3.97 (−1.15) −3.86 (−1.20) |
| Event1 (M&A, 2012–14) | 6.42 (1.68)* 6.42 (1.95)* 5.82 (1.66)* 5.23 (1.74)* |
| Event2 (sale/closure, 2012–14) | −14.9 (−2.57)** −12.6 (−1.98)* −4.51 (−1.18) −4.56 (−1.50) |
| Event3 (outsourcing, 2012–14) | −9.00 (−1.95)* −2.87 (−0.51) −3.75 (−1.18) −0.60 (−0.18) |
| Event4 (new subsid, 2012–14) | 13.2 (3.92)** 15.0 (3.02)** 11.0 (3.77)** 13.7 (3.67)** |
| Type of regression | OLS, robust, and clustered standard errors Quantile, robust, and clustered standard errors Quantile, robust, and clustered standard errors Quantile, robust, and clustered standard errors |
| No. of observations | 4,163 4,163 4,163 4,163 |
| R²/Pseudo R² | 0.07 0.06 0.06 0.05 |

Note: t-statistics shown in parentheses. **, *, denote significance at the 10%, 5% and 1% level, respectively. Industry dummies are included but not reported. The clustered standard errors are calculated following Parente and Santos Silva (2016).

Source: German Community Innovation Survey (CIS) 2014, 2016, Eurostat (2018), Creditreform, own estimations.
### TABLE 4  Circular economy innovations and employment growth in German firms (results of OLS and quantile regressions)

| Regressors                  | Dependent variable: Emp1416 |
|-----------------------------|-------------------------------|
|                             | OLS 25% quantile Median 75% quantile |
| CE innovation (2012–14)     | 2.43 (2.75)** 2.78 (3.51)** 1.06 (2.34)** 1.00 (1.51) |
| Turnov12–14d                | 4.66 (5.13)** 3.86 (5.10)** 3.48 (5.81)** 6.40 (6.89)** |
| Wage1314                    | 0.10 (2.28)* 0.08 (2.90)** 0.08 (4.82)** 2.02 (6.59)** |
| Export (2014)               | 1.08 (1.02) 2.13 (2.25)* 0.06 (0.11) −0.54 (−0.70) |
| Highqual (2013)             | 1.57 (0.69) −0.78 (−0.49) 0.27 (0.24) 6.73 (3.37)** |
| Family (2014)               | 0.66 (0.69) −2.39 (−2.96)** −0.14 (−0.31) 3.00 (4.05)** |
| Pricecomp (2014)            | −2.51 (−2.76)** −2.76 (−3.62)** −1.48 (−3.24)** −2.32 (−3.21)** |
| Size (2012)                 | −0.28 (−1.20) −0.68 (−2.78)** −0.01 (−0.01) −0.09 (−0.20) |
| West (2014)                 | −0.15 (−0.16) 0.85 (1.08) 0.26 (0.58) −0.09 (−0.10) |
| Event1 (M&A, 2012–14)       | 0.15 (0.07) 0.12 (0.09) 0.27 (0.42) −2.95 (−1.08) |
| Event2 (sale/closure, 2012–14) | −7.16 (−3.22)** −5.32 (−2.57)** −3.48 (−3.44)** −2.33 (−1.98)* |
| Event3 (outsourcing, 2012–14) | −4.53 (−2.23)* −3.27 (−2.16)* −1.28 (−1.32) −0.46 (−0.29) |
| Event4 (new subsid., 2012–14) | 3.02 (1.37) 2.05 (0.98) 2.23 (1.68)* 3.89 (1.54) |

| Type of regression           | Quantile, robust standard errors |
|-----------------------------|---------------------------------|
| No. of observations         | 3,145 3,219 3,219 3,219          |
| $R^2$/Pseudo $R^2$           | 0.06 0.02 0.01 0.01              |

Note: $t$-statistics shown in parentheses. +, *, ** denote significance at the 10%, 5% and 1% level, respectively. Industry dummies are included but not reported. Source: German Community Innovation Survey (CIS) 2014, 2016, own estimations.

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### TABLE 5  Circular economy innovations and labor productivity growth in German firms (results of quantile regressions)

| Regressors                  | Dependent variable: Labprod1416 |
|-----------------------------|---------------------------------|
|                             | 25% quantile Median             |
| CE innovation (2012–14)     | 0.08 (0.07) 0.17 (0.20)         |
| Wage1314                    | −0.15 (−3.54)** −0.09 (−2.81)** |
| Export (2014)               | 1.43 (1.04) −0.53 (−0.58)       |
| Highqual (2013)             | −6.81 (−2.38)* 1.36 (0.53)      |
| Family (2014)               | −3.14 (−2.65)** −1.48 (−1.87)*  |
| Pricecomp (2014)            | −1.72 (−1.52) −1.47 (−1.70)*    |
| Size (2012)                 | −0.00 (−0.00) 0.12 (1.00)       |
| West (2014)                 | 0.43 (0.34) −0.25 (−0.25)       |
| Event1 (M&A, 2012–14)       | −3.35 (−2.43)** −2.78 (−1.44)  |
| Event2 (sale/closure, 2012–14) | −5.57 (−3.57)** −0.76 (−0.34)  |
| Event3 (outsourcing, 2012–14) | 3.15 (1.41) 2.70 (1.10)        |
| Event4 (new subsidaries, 2012–14) | −0.32 (−0.20) −0.24 (−0.08)  |

| Type of regression           | Quantile, robust standard errors |
|-----------------------------|---------------------------------|
| No. of observations         | 2,331                           |
| Pseudo $R^2$                | 0.01                            |

Note: $t$-statistics shown in parentheses. +, *, ** denote significance at the 10%, 5% and 1% level, respectively. Industry dummies are included but not reported. Source: German Community Innovation Survey (CIS) 2014, 2016, own estimations.

Separate estimations of the employment model for manufacturing and services as well as for smaller and larger firms (see Table S2 in the Supporting Information) do not show relevant differences concerning the role of CE innovations. The coefficients for the CE innovation variable are in all subsamples (at least weakly) statistically significant. This means that the positive link between CE and employment applies to different types of firms in a similar way.
7 | CONCLUSIONS

This paper looked at the link between CE innovations, and firm growth and performance. For a representative panel sample of German firms, we analyzed whether CE innovation are positively or negatively linked to a subsequent change in firms’ turnover and employment as well as the firms’ financial standing and productivity growth. For environmental policy, this is an important question. In order to transit economic activities to more sustainable paths, firms need to change the way they produce and distribute goods and services. If such a change was at the expense of lower growth and worsened competitiveness, policy would need to implement costly incentives. However, if CE innovations are positively associated with growth and performance, policy could focus on instruments that require the introduction of CE innovations fast and broadly. In such a case, CE innovations would not only contribute to the environmental dimension of sustainability, but also to the social one, as they would lead to higher levels of employment.

Our econometric estimations support the view that CE innovations, growth, and performance go hand in hand. Firms with CE innovations during 2012 and 2014 experience significantly higher sales and employment growth in the subsequent period 2014–2016 as compared to other firms in their sector. At the same time, they show a significantly better financial standing in 2016, while there is no statistically significant impact on labor productivity. CE innovations, at least in the case of Germany and during a period of stable macroeconomic growth, spur the demand for the innovators’ products. In order to serve this demand, firms expand production and hire additional workers. The higher costs associated with the expansion of employment seem to be offset by higher prices for CE-based products, as revealed by the positive results for the firms’ financial standing. CE innovations themselves seem to rest on neither a labor nor capital saving technological change, as we do not find significant impacts on labor productivity growth.

For environmental policy, our results imply that instruments that require firms to adopt CE approaches can build upon positive returns from CE innovations at the firm level. Such a situation would call for smart regulation, which requires firms to adopt novel CE approaches. Examples for such a policy approach include requirements for longer product lifetimes and an easier repair and recyclability of products, or requirements to continuously increase energy and material efficiency in production processes. By pushing innovations that contribute to the principles of a circular economy, governments can create a win-win situation of the Porter-hypothesis type, as long as demand is acknowledging such innovations through a higher propensity to buy or a higher willingness to pay for CE-based products. It is therefore essential to combine CE-oriented regulation with policies to inform users about the long-term benefits of a transition toward the circular economy. Eco-labels or CSR approaches of firms could be useful in this respect (see also Reif & Rexhäuser, 2018).

The present paper contributes to our understanding of the role of CE for the competitiveness of firms and the firms’ labor demand. However, the results are limited to a specific country and time period and only capture CE innovations of firms. Furthermore, our findings have to be interpreted very carefully because our definition of CE innovation is based on the specific taxonomy of CE innovations provided by the CIS. For future research, analysis for other countries and time periods would be helpful to broaden the empirical foundations for CE-oriented policies. The CIS provides a good starting point to do similar research for other countries than Germany, though firm panel data would be required, which are not available for most countries participating in the CIS. In addition, the role of households needs to be examined in more detail in order to shed light on the interplay between household demand and firm behavior (see, e.g., Verplanken, 2018).

ACKNOWLEDGMENTS

The authors would like to thank three anonymous referees for their valuable comments.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ORCID

Jens Horbach  
https://orcid.org/0000-0003-2034-7258

Christian Rammer  
https://orcid.org/0000-0002-1173-9471

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**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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**How to cite this article:** Horbach J, Rammer C. Circular economy innovations, growth and employment at the firm level: Empirical evidence from Germany. *J Ind Ecol.* 2020;24:615–625. [https://doi.org/10.1111/jiec.12977](https://doi.org/10.1111/jiec.12977)