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DISCUSSION PAPER

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The Impact of the EU General Data Protection Regulation on Innovation in Firms

The Impact of the EU General Data Protection Regulation on Innovation in Firms

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Abstract

In May 2018, a new regulation by the European Commission on data protection came into force, the General Data Protection Regulation (GDPR). It requires many firms to update their data protection strategy. It may also complicate different types of data usage, particularly related to data on individuals. In the literature, there is little evidence and no consensus on whether this new privacy regulation is beneficial or detrimental to innovation. This study provides empirical evidence on the impact of the GDPR on innovation activities in firms. Exploiting panel data from the German innovation survey, a difference-in-difference analysis shows that the GDPR stimulated additional innovation activity while shifting the focus of innovation away from radical and towards more incremental innovation. This holds for both firms that report that the GDPR complicated their innovation efforts, and for the much smaller group of firms that report that the GDPR facilitated their innovation activities. Finally, larger and older firms experience higher increases in their turnover with incremental innovation compared to smaller and younger firms.

JEL-Classification: O31, O38, C22, L51

Key words: General Data Protection Regulation, Innovation, Community Innovation Survey, Difference-in-difference estimation

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1. Introduction

In 2018, the General Data Protection Regulation (GDPR) came into force. The GDPR aims to protect consumers and give them more control of their data. The GDPR applies to organisations that control and process data of EU citizen's regardless as to where the organisation is located. The regulation is aimed at not only tackling increasing public concern regarding the protection of personal data but also to instil consumer trust in the digital economy and providing space for the digital economy to grow (see ITU and World Bank 2020). Indeed, the GDPR aims to secure competition in markets related to personal data. The GDPR is particularly relevant to companies operating large digital platforms. Due to their market dominance based on the privileged access to consumer data as well as becoming invaluable to their customers as a result of network effects, these companies are in a position to disregard consumer concerns and stifle competing innovation without significant repercussions (Geradin et al. 2021).

As the regulatory and policy-making environment attempts to adapt to novel features and concerns presented by the digital economy, the GDPR is a trailblazer as a digital regulation. There has been significant debate as well as speculation regarding the effect of the GDPR on innovation (negative effect see Goldberg et al. 2019, Jia et al. 2021, see Wallace and Castro 2018 and positive effect see Arcuri 2020, Cisco 2019, Von Grafenstein 2019). Much of this debate rests on blanket arguments (see Wallace and Castro 2018), however, without sufficiently analysing the real effects in detail, particularly with regards to innovation. Our analysis attempts to fill this gap by investigating the effect of the introduction of the GDPR on innovation in firms. In particular, we analyse which type of innovation is stimulated or hindered, and which types of firms are affected. Based on firm-level panel data from the German Community Innovation Survey (CIS), we employ a difference-in-difference setting in order to identify changes in innovation performance prior and after the introduction of the GDPR in firms that report that they were affected by GDPR and firms that were not affected. Since the GDPR has been introduced in 2018 only, and our data cover just three years since then (2018 to 2020), our results are limited to short-run, direct impacts of the new regulation. Medium to long-run impacts as well as indirect effects are beyond the scope of this paper.

Our empirical results reveal that a large majority of the surveyed firms perceive the GDPR as a barrier to innovation, whereas only a small share concentrated in the information and communication sector and financial services report an innovation supporting impact. The difference-in-difference analysis shows that the GDPR stimulated additional innovation activity, while shifting the focus of innovation away from radical towards incremental innovation. This holds for both firms that report that the GDPR complicated their innovation efforts, and for the much smaller group of firms that report that the GDPR facilitated their innovation activities. Finally, larger and older firms experience higher increases in their turnover with incremental innovation compared to smaller and younger firms.

The remainder of the paper is structured as follows. After the review of the limited literature, we derive our research questions. Then, we present our data and the descriptive statistics. Following the elaboration of our empirical strategy, we display the results of our estimations, which are then discussed in the following chapter including the limitations of our approach. We close with the main conclusions, but also first policy implications.

2. Literature Review

The discussion around the impact of data protection regulation − or privacy regulation as it is often called in the US literature − on innovation is layered. On a broad level, it is situated in the discussion regarding the impact of regulation on innovation. On the one side, regulation is seen as a restriction to firms' decision on how to operate business activities − either through raising costs or by complicating or impeding certain activities, resulting in negative impacts on innovation. On the other side, regulation is perceived to be able to also have a positive effect on innovation, such as by stimulating innovative adaptations to a new situation or market opportunities created by a regulation. Within this sphere of thought, the 'Porter hypothesis' stands out as describing under which conditions a regulation − in this case an environmental one − can be beneficial for firms' innovation and competitiveness (Porter and van der Linde 1995).

With a more specific focus on the literature regarding the impact of data protection regulation on the economy and innovation there are those scholars that argue its impact is negative. Posner (1978, 1981) and Stigler (1980) outline how privacy regulation leads to negative traits and inefficiencies by removing vital information from the market. With particular reference to the GDPR's impact on innovation, some scholars have pointed to a negative impact (Goldberg et al. 2019, Jia et al. 2021). Goldberg et al. (2019) depict a 12% decrease in page views and revenue for the EU users. Jia et al. (2021) find a negative effect in terms of less venture capital invested in the EU compared to the US after the implementation of the GDPR.

The effects of data protection regulation and in particular, the GDPR's impact on competition and small and medium sized enterprises (SMEs) has been a significant point of discussion. There are those who argue that privacy regulation has a negative effect on competition leading to market concentration and disadvantaging SMEs (see Marthews and Tucker 2019, Phillips 2018). Some have focused particularly on the negative impact of the GDPR strengthening the positions of the dominant tech players (Campbell et al. 2015, Geradin et al. 2021, Johnson et al. 2020, Peukert et al. 2022).

Of particular relevance for this paper is research regarding firms. There is indeed, very little research actually concretely analysing the impact of the GDPR at the firm level. Here, in terms of negative impact, there is Koski and Valmari (2020) looking at the short-term impact on firms' financial performance noting less profit margins in the EU compared to the US, where SMEs were seen to be more disadvantaged. There is Chen et al. (2022), who outline how for those firms with European consumers, data protection regulation has led these firms to experience a two percent sales reduction and a decline of profits of eight percent. Furthermore, some critics mention the 'privacy paradox' namely, that despite consumers stating their desire for better privacy protection their choice of using online services, which intrude significantly on their privacy, suggests that in reality, this is not the case. That if it were so vital to consumers, a competitive market would provide the privacy-orientated alternatives (see Marthews and Tucker 2019) and that subsequently, data protection regulation is not required.

Regarding the impact as a whole of the data protection regulation on innovation, there are then those that argue that the impact is positive (see Cisco 2020, Cohen 2013, Richards 2008). Cohen (2013) outlines how central privacy is for innovation by providing the space for experimentation and play that is crucial for innovation. Furthermore, privacy is vital for a rich culture, creativity and intellectual development. Similarly, Richards (2008) underlines the importance of privacy or rather 'intellectual privacy' in providing the freedom to explore novel ideas and overall, plays a crucial role for free speech. Specifically regarding the GDPR's impact, there are those who point to its positive impact (Arcuri 2020, Cisco 2019, Von Grafenstein 2019). Arcuri (2020) takes a sectoral approach and outlines the positive reaction of the EU financial market to the GDPR. Cisco (2019) shows that those companies that are 'GDPR-ready' see large positive returns such as fewer data breaches, which − if they do occur − are less significant as well as entailing lower system downtime.

There is then the literature that disputes these claims of the negative impact with regards to competition and SMEs. For example, Richardson (2019) strongly questions this stating that there is no clear evidence of this in the EU, where she outlines how it is rather the digital advertising and data marketplaces that have been significantly affected, which were at the core of several privacy scandals (e.g. Facebook-Cambridge Analytica). Research has highlighted how when it comes to individual decision-making about privacy, certain cognitive as well as structural characteristics stand out that contradict the privacy paradox, underlie the importance of having data protection regulation, and how without which, effective competition is being compromised (Acquisiti et al. 2016, Kemp 2020, Solove 2013). Acquisiti et al. (2016), highlights that when individuals make decision with regards to their privacy they discount the future costs for immediate gain leading to myopic decision-making. Most importantly, without full knowledge about what data about them is being held and how it can be used, individuals are unaware of all costs.

In terms of how data protection regulation can have a positive impact on competition, Kemp (2020) outlines how 'concealed data practices' used by firms to gather as much as consumer data as possible, undermines privacy-orientated competitors and their innovations. At the firm level, Martin et al. (2019) captures start-up responses to data protection regulation including the GDPR. The GDPR was found to have unleashed innovation-stimulating effects on start-ups- undermining arguments highlighting how negatively affected SMEs are- where there was also suggestions of innovation-constraining effects though these were less apparent and often were to be expected (e.g. socially problematic innovations). That innovation-stimulating effects were found for start-ups particularly relevant to the discussion regarding the GDPR's impact on SMEs. Campbell et al. (2015) criticism that market concentration will ensue as a result of users more readily giving consent to the more established trusted large platforms not only underestimates users increasing distrust of Big Tech but furthermore, points rather to issues with the 'notice and consent' or 'notice and choice' in the US (Kemp 2020, Hull 2015, Solove 2013). Solove (2013) terms the privacy framework based on getting consent and consumers making decisions regarding their privacy as 'Privacy self-management' and criticizes this framework heavily as a result of cognitive and structural problems. However, whereas this framework still dominates in the US and consent is still one of the significant legal basis for the processing of personal data under the GDPR (among others), the conditions of valid consent are quite strict. Moreover, they accommodate some of the cognitive and structural issues that plague individual decision-making about privacy (e.g. Article 4(11) consent must be 'freely given' where there needs to be a real choice provided or where the subject is required to have been sufficiently 'informed'). There are also arguments that the status quo in the digital economy suffers from concentrated market power and monopoly concerns or rather 'data-polies' (see Ezrachi and Robertson 2019, Stucke 2018, Robertson 2019). Indeed, that through the accumulation of personal data, these data-polies have large negative consequences on privacy protection, competition, innovation and society as a whole (ibid). The status quo of the digital economy and the increasing strength of the Big Tech companies leads to competitions concerns, requiring subsequent governmental action and intervention. Niebel (2021) provides an outline on how indeed, the GDPR tackles concentrated market power concerns, how as a well-crafted regulation it can promote innovation in alignment with the Porter Hypothesis and how its extraterritorial nature means that it does not put EU companies at a competitive disadvantage.

A notion that has also emerged in the literature, however, is that the effects of privacy regulation does not have one overarching impact but rather is context dependent where its impact can be positive and negative particularly, in terms of societal and individual welfare impact (Acquisiti 2010, 2016, Adjerid et al. 2016). Adjerid et al. (2016) looks at the case of Health Information Exchanges (HIE), where privacy regulation on its own is found to limit the HIE, but when combined with incentives, privacy regulation has a positive impact on HIEs. Overall, they conclude that the impact of privacy regulation on innovation is 'heterogeneous' namely can be positive or negative depending on the particular characteristics of the privacy regulation. This last point, where the impact can be either positive or negative, depending on the context is also highlighted by Acquisiti (2016), particularly in regards to societal and individual welfare.

Based on the ambivalent insights from the literature review, we derive the following research questions:

1. Did GDPR lead to more or less innovation, particularly what type of innovation was stimulated by the GDPR, what type of innovation was hampered?
2. How were different types of firms affected, e.g. SMEs vs. large firms, industry vs. services, data-oriented firms vs. non-data-oriented firms?

3. Data and descriptive results

Data source

Our empirical analysis rests on a unique data source on the role of privacy regulation for a firm's innovation activities. The data have been collected through the German part of the European Commission's Community Innovation Survey conducted in the year 2019 and obtaining information on a firm's innovation activities for the reference year 2018 ('CIS 2018'). The harmonised questionnaire of the CIS 2018 contained a question on the role of legislation and regulation for the innovation activities of firms, separating positive impacts (initiating or facilitating of innovation activities) and negative ones (preventing or hampering innovation activities). The harmonised questionnaire distinguished the following areas of legislation/regulation: product safety & consumer protection, environmental protection, intellectual property, taxation, employment law, and worker safety & social affairs. In the German questionnaire for the CIS 2018, another area 'data protection' was added. Figure 1 shows the design of the question used in the German CIS 2018.

Figure 1: Question on the role of legislation and regulation on innovation in the German CIS 2018

8.1 During 2016 to 2018, has legislation or regulation affected your enterprises' R&D/innovation activities in any of the following ways?

(Tick all that apply)

Legislation/regulation on ...	R&D/innovation activities were ... initiated/ facilitated	prevented/ hampered	No effect on R&D/innovation activities
Product safety, consumer protection	☐ 1	☐ 1	☐ 1
Environmental protection, climate protection	☐ 1	☐ 1	☐ 1
Intellectual property	☐ 1	☐ 1	☐ 1
Data protection	☐ 1	☐ 1	☐ 1
Employment law	☐ 1	☐ 1	☐ 1
Worker safety, social affairs	☐ 1	☐ 1	☐ 1
Taxation	☐ 1	☐ 1	☐ 1

Though the survey form did not make explicit reference to the GDPR (as it did not make any reference to specific legislation or regulation), the introduction of the GDPR in May 2018 was the only major legislative event during the reference period of the question. As the GDPR overruled all major prior privacy regulation in Germany, we can safely assume that firms were referring to the GDPR when reporting positive or negative innovation consequences of data protection regulation.

Differently to most other national CIS, the German CIS is designed as an annual panel survey and called the Mannheim Innovation Panel (MIP). It surveys the same sample of firms (with a panel sample refreshment every second year) and collects information beyond the standard information of the CIS, including more information on financial variables (see Peters and Rammer 2013 for more details on the MIP). The panel nature of the survey enables the analysis of innovation activities of firms before and after the introduction of the GDPR. Together with the information on whether firms' have been affected by the GDPR (using information from the question shown above), this allows a difference-in-difference (DiD) design for identifying likely impacts of the GDPR on innovation.

Descriptive results

Before presenting and discussing the DiD estimation, we present descriptive results of the role of the GDPR for innovation in firms. We use weighted results of the question on whether data protection regulation initiated/facilitated or prevented/hampered innovation activities. The results are broken down by size class, industry and type of innovation activity (see Table 1).

The first point that stands out is that less than half (39.7%) of the firms stated that the GDPR had an effect on their innovation activities. Of those, the majority (35.0%) stated it would complicate innovation, whereas only 4.7% stated it would facilitate innovation. The firms with the highest share stating that the GDPR would complicate innovation were firms with 1,000 or more employees. The firms with the highest share stating that the GDPR would facilitate innovation were relatively large companies (500-999 employees). This result does not support the many claims outlining how the GDPR has a particularly negative effect on SMEs compared to the larger firms (see Bessen et al. 2020, Campbell et al. 2015, Geradin et al. 2021, Peukert et al. 2022, Phillips 2018).

The highest share in terms of share of firms stating that the GDPR constrains innovation is for ‘financial services and insurance’ (58.5%). However, conversely, this industry also has one of the highest share of firms stating that it is facilitating innovation (11.3%). Financial services have to deal with a significant amount of data, which explains the constraining perception, however, trust, reputation, and cybersecurity is also essential for the well-functioning of financial services and underlines positive reactions to the GDPR (see Arcuri 2020). ‘Publishing, printing, motion picture and broadcasting’ also reports a higher percentage share (48.2%) regarding constraining innovation, which most likely reflects the opinions of publishers. Indeed, it might be explained by the fact that traditional uninterrupted tracking such as with cookies (see Peukert et al. 2022) without getting active consent from users in collecting their personal information for advertising revenue is no longer accepted. This comes as no surprise as the GDPR‘s aim is to also limit this kind of behind-the-scenes tracking which has been the reason for a lot of privacy scandals and undermines consumer trust. However, other publishers see the GDPR as an opportunity. For example, the vice president of advertising data of the New York Times stated that “It’s a win-win-win: Publishers regain control of the segmentation and classification of their impressions and cut out costly middlemen peddling questionable data. Consumers get a privacy-friendly environment where they don’t need to second-guess what they did to prompt a certain ad. And advertisers have safe targeting methods that can often beat conventional behavioral targeting” (AdExchanger 2019).

The highest share reporting the GDPR having an innovation-facilitating effect is the industry ‘Telecommunications, computer & information services’ (14.7%). Furthermore, they have a relatively low percentage share who respond that the GDPR constrains innovation (35.4%). This is interesting insofar as this is a sector that the GDPR is aimed to regulate and could be a signal that an increase in consumer trust via regulation is somewhat welcomed by these industries.

With reference to innovation activities, innovation active firms are more often affected by the GDPR compared to firms not engaging in innovation activities. There is no significant difference between product and process innovators, but there are notable differences by the type of innovation. Firms with service innovation are more affected than firms with goods innovation, mirroring the increasing role of digitalisation for service innovation. Among process innovators, firms with innovations in workplace organisation report the highest share of negatively affected firms. Indeed, the GDPR would have a significant impact here, setting up the mechanisms not only in dealing with employee and consumer data, but also in its protection from breach and setting up the response mechanisms in case of one. In addition, not only workforce training regarding protecting personal data but also new positions for Data Protection Officers would further change the workplace organisation. However, such upheaval is not necessarily bad, where a company increasing its cybersecurity and streamlining its data collection and processing can result in significant financial returns (Cisco 2020). Indeed, this can explain the highest percentage of the share of firms stating that there is an overall impact being from ‘Process innovators: administrative procedures’ where despite the constraining effect being marked relatively high (48.7%) so is its facilitating effect (10.4%).

Table 1 Share of firms reporting GDPR impact on innovation

	GDPR is **facilitating** innovation ('positive effect')	GDPR is **complicating** innovation ('negative effect')	Either **positive or negative** effect on innovation
All firms	4.7	35.0	39.7
Size classes			
5 to 9 employees	3.3	32.9	36.2
10 to 19 employees	4.7	36.6	41.2
20 to 49 employees	5.5	35.4	40.9
50 to 99 employees	6.3	37.0	43.3
100 to 249 employees	7.4	35.8	43.2
250 to 499 employees	6.9	39.6	46.4
500 to 999 employees	9.4	36.3	44.9
1000+ employees	7.8	40.5	47.4
Industries			
Manuf. of food, beverages & tobacco	2.2	29.6	31.7
Manuf. of textiles, clothing & leather products	2.5	27.2	29.7
Manuf. of wood & paper products	2.2	28.0	30.3
Manuf. of chemicals & pharmaceuticals	3.0	31.9	34.8
Manuf. of rubber & plastic products	5.9	19.3	25.2
Manuf. of glass, ceramics & concrete	4.4	27.2	32.0
Manuf. of metals & metal products	2.8	27.3	30.1
Manuf. of electronics & electrical equipment	3.7	33.8	37.5
Manuf. of machinery	4.4	28.4	32.8
Manuf. of vehicles	1.3	28.9	30.2
Manuf. of furniture & other consumer products	4.1	35.6	39.7
Energy supply, manuf. of petroleum & mining	2.0	31.0	33.0
Water supply, sewerage & waste management	3.6	24.3	27.9
Wholesale trade	6.3	35.4	41.7
Transport, storage & postal services	2.6	28.1	30.7
Publishing, printing, motion picture & broadcasting	4.5	48.2	52.7
Telecommunications, computer & information services	14.7	35.4	49.5
Financial services & insurance	11.3	58.5	69.8
Engineering & R&D services	1.0	37.0	38.0
Consultancy & advertising	5.0	43.0	48.0
Other business-oriented services	4.4	40.5	44.9
Innovation activities			
Innovation active firms	7.0	43.1	50.0
Non-innovation active firms	0.7	21.0	21.7
Product innovators	8.9	45.2	53.9
Process innovators	7.9	44.6	52.4
Goods innovators	8.1	44.5	52.5
Services innovators	10.5	47.9	58.4
Process innovators: production technology	9.7	47.1	56.7
Process innovators: logistics	6.7	47.4	54.1
Process innovators: IT	8.9	46.5	55.3
Process innovators: administrative procedures	10.4	48.7	59.1
Process innovators: organisational method	9.4	45.7	55.0
Process innovators: workplace organisation	8.4	49.9	58.2
Process innovators: marketing methods	6.7	48.2	54.9

Source: German Innovation Survey 2018, weighted results.

Innovation output of firms does not differ significantly among firms affected by the GDPR and those that were not. The share of sales from product innovation was 14.7% in 2018 among firms affected by the GDPR, and 14.5% among those not affected (Table 2). Interestingly, firms reporting negative impacts from GDPR show a higher sales share (14.9%) compared to those reporting a positive impact (13.2%). For the subgroup of new-to-market innovations, the sales shares are almost the same for both types of affectedness as well as for those firms not affected. More substantial differences are found with respect to cost savings from process innovation, which are highest among firms reporting negative GDPR impacts (4.0%) and lowest for not affected firms (3.0%).

Table 2 Innovation output and affectedness by the GDPR

	GDPR is **facilitating** innovation ('positive effect')	GDPR is **compli cating** innovation ('negative effect')	Either **positive or negative** effect on innovation	Innovation **not affected** by GDPR
Sales share of product innovations (%)	13.2	14.9	14.7	14.5
Sales share of new-to-market innovations (%)	3.1	3.3	3.3	3.4
Sales share of only new-to-firm innovations (%)	10.1	11.5	11.4	11.1
Share of cost reduction from process innovation (%)	3.7	4.0	4.0	3.0

Source: German Innovation Survey 2018, weighted results.

In summary, the descriptive statistics reveal that the companies' perception on the influence of the GDPR differs not so much between companies of different sizes or following different innovation strategies, but significantly between companies of different sectors. On the one hand, the sector-specific relevance of the GDPR has been revealed in the literature such as for example, its positive reception from the financial sector (Arcuri 2020), but less so for certain actors in e-commerce (Goldberg et al. 2019). One the other hand, the findings do not reveal size-specific affectedness of the GDPR contradicting the higher burden for SMEs stated by Marthews and Tucker (2019) or Phillips (2018). Overall, the perception of the impact of GDPR is more sector specific and less company-size or innovation-type specific.

4. Empirical Strategy

Model set-up

In order to identify the impact of the introduction of the GDPR by the European Commission in 2018 on innovation, we employ a difference-in-difference (DiD) estimation approach. We use firm-level panel data on innovation output (*INOUT*) prior and after the introduction of the GDPR together with information on whether a firm's innovation activities have been affected by the GDPR, either positively or negatively. We construct two treatment variables: *GDPR_OB* takes unit value if a firm reported (in 2019) that data protection regulation constitutes an obstacle for innovation by preventing or hampering innovation activities. *GDPR_SU* takes unit value if data protection regulation was supportive to the firms' innovation efforts by initiating or facilitating innovation activities. Both variables can take unit value only from the year of GDPR introduction in 2018 and have the value zero for all years prior to 2018. For firms not affected by the GDPR, both variables have zero value in all years.

We estimate a firm fixed-effect model that reads as follows:

$$(1) \quad INOUT_{it} = \alpha + \beta_1\, GDPR\_OB_{it} + \beta_2\, GDPR\_SU_{it} + \chi\, \mathbf{Z}_{it} + \delta\, \mathbf{t} + \gamma\, \mathbf{i} + \varepsilon_{it}$$

The coefficients β_1 and β_2 show the effect of the introduction of the GDPR on innovation output. Vector **Z** represents a set of control variables that may affect *INOUT*, including innovation inputs, digitalisation efforts and the general level of resources of a firm. The model includes time dummies **t**, firm fixed-effects **i** and a constant (α). ε denotes a firm-specific and time-specific error term.

Measurement of model variables

Innovation output is measured for both product and process innovation. For product innovation, we use the share of sales obtained from product innovation, distinguishing new-to-the-market ('radical') innovations (*INS_M*) and innovations that were only new-to-the-firm ('incremental innovation' or 'imitations') (*INS_F*). This information can be directly obtained from the CIS questionnaire and is collected on an annual bases in the German CIS. The sales share indicator on product innovation output have widely been used in the literature (see Mairesse and Mohnen 2002, Laursen and Salter 2006, Leiponen and Helfat 2010, Klingebiel and Rammer 2014). For process innovation output, we use the share of unit cost reduction owing to process innovation (*INS_C*). This indicator has less widely been used in the literature since it is not part of the standards set of innovation indicators collected in the CIS. Some countries, including Germany, have included this indicator in their national surveys (see Rammer 2022), which has produced reasonable results in different research settings (see for example Piening and Salge 2015, Rammer et al. 2022).

Innovation inputs are measured by the volume of innovation expenditures (in constant prices using the GDP deflator) per full-time employee, distinguishing two types of expenditure: R&D

expenditures (*RDINP*) and other innovation expenditures (*NRDINP*). *RDINP* identifies the amount of resources that are devoted to generating new knowledge, whereas *NRDINP* refers to the resources used for implementing new knowledge in new products and processes, such as design, market introduction and other preparatory work. Digitalisation efforts (*DIG*) are measured as expenditures for software and databases (in constant prices using the GDP deflator) per full-time employee. *DIG* includes both in-house costs and purchase of software programmes, software licences, software programming services and databases. *RDINP*, *NRDINP* and *DIG* enter the model as lagged variables (i.e. measured for t-1) in order to account for the time that is required to transfer inputs to innovation outputs.

A firm's general resource endowment is measured by the number of full-time employees (*EMP*), its age (*AGE*) and human capital intensity (*HC*, measured as the share of graduated employees), *EMP* and *AGE* are transformed into log-values. In addition, we include the lagged value (measured in t-1) for a firm's export share (sales to customers abroad in total sales, *EXP*) in order to control for likely effects on business activities abroad on the way the GDPR affects innovation. Such effects may occur due to national differences in the implementation of the GDPR, as well as by the fact that firms selling products outside the EU are not directly affected by the GDPR when interacting with their non-EU customers. Note that by estimating fixed-effects models, we already account for firm-specific effects on innovation output that arises from a firm's capabilities and accumulated assets.

The model variables are measured for the time period 2011 to 2020. The starting year is determined by the fact that this was the first year that the MIP collected data on software and database expenditure. The last year 2020 is the most recent year available at the time of analysis. The total number of observations for model estimations is 28,761 for product innovation output (representing 6,349 different firms) and 28,804 for process innovation output (representing 6,363 different firms). Table 3 informs about the definition and descriptive statistics of model variables.

Table 3 Definition and descriptive statistics for model variables

Variable	Definition	# obs.	Mean	SD	Min	Max
INS_F	Share of sales from product innovation that were only new to the firm	28,761	0.0541	0.1425	0.0	1.0
INS_M	Share of sales from product innovation that were new to the firm's market	28,761	0.0159	0.0764	0.0	1.0
INS_C	Share of unit cost reduction owing to process innovation	28,804	0.0093	0.0398	0.0	1.0
IN_F	1 if firm has introduced a product innovation only new to the firm, 0 otherwise	28,761	0.2443	0.4297	0.0	1.0
IN_M	1 if firm has introduced a product innovation new to the firm's market, 0 otherwise	28,761	0.1062	0.3080	0.0	1.0
IN_C	1 if firm has introduced a cost-reducing process innovation, 0 otherwise	28,804	0.1079	0.3102	0.0	1.0
INS_F	for IN_F>0	7,027	0.2214	0.2146	0.00010	1.0
INS_M	for IN_M>0	3,053	0.1500	0.1870	0.000001	1.0
INS_C	for IN_C>0	3,107	0.0863	0.0896	0.00020	1.0
GDPR_OB	1 if firm reported that data protection regulation has complicated innovation activities, 0 otherwise	27,261	0.1116	0.3148	0.0	1.0
GDPR_SU	1 if firm reported that data protection regulation has facilitated innovation activities, 0 otherwise	27,261	0.0150	0.1217	0.0	1.0
RDINP	R&D expenditures (at 2015 prices) per full-time employee (million Euro)	28,761	0.0023	0.0073	0.0	0.05
NRDINP	Non-R&D innovation expenditures (at 2015 prices) per full-time employee (million Euro)	28,761	0.0017	0.0063	0.0	0.08
DIG	Expenditures for software and databases (at 2015 prices) per full-time employee (million Euro)	28,761	0.0008	0.0019	0.0	0.01
EXP	Share of export sales in total sales	28,761	0.1190	0.2267	0.0	1.00
EMP	No. of full-time employees (log)	28,761	3.1245	1.5171	-0.6931	11.98
AGE	No. of years since firm foundation (log)	28,761	3.1734	0.7953	-0.6931	6.20
HC	Share of gradated employees	28,761	0.2350	0.2784	0.0	1.00

In order to identify differences in the impact of the GDPR on innovation across types of firms, we run split models by size, age and sector. With respect to size, we separate the sample into very small firms (less than 20 employees), small to medium-sized firms (20 to less than 100 employees) and medium-sized to large firms (100 or more employees), based on the average number of employees of a firm during the observation period 2011 to 2020. For firm age, we split the sample into young firms (up to 15 years), medium old firms (16 to 30 years) and old firms (more than 30 years), based on the firm's average age during the observation period. In terms of sectors, we consider three types of sector classifications. According the dominant group of customers, we separate B2B industries (firms mainly supply other firms) and B2C industries (firms mainly supply consumers). As a second grouping, we distinguish manufacturing industries (incl. mining) and services (including energy and water supply, recycling, construction, trade). Finally, we separate knowledge intensive and not knowledge intensive industries based on the R&D intensity of manufacturing sectors (following the OECD classification, see Galindo-Rueda and Verger 2016) and the share of graduated employees in service industries.

As the innovation output variables contain many observations with the value zero (for all firms with no product innovations), we estimated two model variants. Variant 1 uses observations for all firms (i.e., including zeros for *INS_M* and *INS_F* in case a firm has no product innovations, and for *INS_C* in case a firm has no process innovations). Variant 2 splits the innovation output variables into a dichotomous 0/1 variable (having new-to-market product innovation *IN_M*, only new-to-firm product innovation *IN_F* or cost reducing process innovation *IN_C*) and a continuous variable (*INS_M, INS_F* and *INS_C*), restricting the estimations on *INS_M, INS_F* and *INS_C* to firms that have introduced the respective type of innovation (i.e., for *INS_M* if *IN_M*>0, etc.). For all models, fixed-effect OLS regressions are used, including the dichotomous dependent variables.

5. Estimation results

Base model

The base model estimations for all firms (Table 4) show that the impact of GDPR on innovation varies significantly by type of innovation output. Firms that report that the GDPR hampered or prevented innovation activities show a higher sales share of new-to-firm innovations whereas the sales share of new-to-market innovations went down by 0.6 percentage points. Both effects are significant at the 5% confidence level. The same pattern is found for firms that report a positive consequence of the GDPR on innovation. Their sales share of new-to-firm innovations went up by 3.3 percentage points, while new-to-market sales share decreased by 1.5 percentage points (the latter effect shows a weaker level of significance, however). This result implies that the GDPR has shifted innovation towards a lower level of novelty, regardless on whether the regulation stimulated or hampered innovation activities in affected firms. The GDPR hence facilitated the marketing of incremental changes and the imitation of product innovations that have been introduced by other firms before. At the same time, it complicated more radical innovation. For process innovation output, we find a positive, but not statistically significant impact of the GDPR on cost reduction for firms reporting that the GDPR complicated their innovation activities, and no effect for firms reporting a positive innovation impact of the GDPR.

Table 4 Results of fixed-effect DiD panel estimations on the effect of GDPR on innovation output (model variant 1)

	INS_F (1)	*INS_M* (2)	*INS_C* (3)
GDPR_OB	0.009**	-0.006**	0.002
	(0.005)	(0.003)	(0.001)
GDPR_SU	0.033**	-0.015*	-0.003
	(0.013)	(0.008)	(0.005)
RDINP in t-1	-0.378	0.277	0.025
	(0.322)	(0.296)	(0.084)
NRDINP in t-1	0.519***	0.159	0.151**
	(0.181)	(0.163)	(0.063)
DIG in t-1	0.930	-0.791	0.135
	(0.930)	(0.515)	(0.270)
EXP in t-1	-0.002	-0.006	-0.003
	(0.013)	(0.010)	(0.003)
EMP	0.007**	-0.000	0.001
	(0.003)	(0.002)	(0.001)
AGE	-0.008	-0.012***	-0.002
	(0.008)	(0.005)	(0.002)
HC	0.012	-0.001	-0.001
	(0.009)	(0.004)	(0.003)
Constant	0.057**	0.056***	0.013*
	(0.029)	(0.016)	(0.007)
No. observations	28,761	28,761	28,804
No. firms	6,349	6,349	6,363
R-squared	0.008	0.006	0.004
Year dummies	Yes	Yes	Yes

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

For the control variables, we find a significant positive impact of non-R&D innovation expenditures on the sales share from incremental product innovation and on cost reduction owing to process innovation. We do not find a significant positive effect of R&D expenditures in our fixed-effect models, suggesting that the ability of a firm to successfully commercialise new-to-market innovations is not depending on their actual expenditure for producing new knowledge, but rather on other firm-specific assets and capabilities. We also do not find a significant contribution of expenditures on software and databases on innovation outcome. Among the other control variables, size shows a positive effect on incremental innovation while age shows a negative one on new-to-market innovation. All in all, the control variables have little effects on innovation outcome, suggesting that it is unobserved firm heterogeneity such as management capacity, organisational capabilities, employee skills or accumulated knowledge (all captured by the fixed-effect estimation), which drives the observed variance in innovation outcome among firms, but not short-term changes in input variables.

As robustness checks, we also run alternative model specifications both with a smaller set of control variables and with and extended set of controls, considering the credit rating that a firm has been assigned by by *Creditreform*, Germany's largest credit rating agency (which captures the firm's access to external funding through loans), capital expenditures for fixed assets per full-time employee (representing the firms efforts to update or extend its technical equipment, including machinery and ICT hardware), and marketing expenditures per full-time employee (indicating efforts to promote product sales). The additional control variables did not exert a statistically significant effect on innovation output, and their inclusion did not alter the coefficients for our key model variables, but reduced the number of observations and hence the representativeness of the data. For this reason, we excluded the additional controls in our final estimations.

The results for the innovation-initiating effects (columns 1 and 3 in Table 5) reveal that the GDPR led to an increase in the firms' propensity to introduce incremental product innovation or product innovation that were imitations of already existing innovations, while it had no effect on the propensity to introduce radical product innovations. The effect on incremental innovation is much stronger for firms that reported a positive impact from GDPR on their innovation activities. The probability to introduce an incremental product innovation increases by 12.7 percentage points. But also firms reporting that the GDPR complicated their innovation activities experienced a 4.6 percentage points higher propensity to introduce incremental innovations. With respect to cost reducing process innovation, firms affected by the GDPR are significantly more likely to introduce such innovations. Again, the effect is slightly higher in case the firms reported a positive impact (+6.6 percentage points) compared to a negative impact from the GDPR (+4.5 percentage points).

When looking at the continuous part of the innovation outcome variables (columns 4 to 6 in Table 5), we find a negative effect of GDPR on the sales share for new-to-market innovations and on cost reduction in case firms reported a positive innovation impact from the GDPR. For firms reporting a negative impact of GDPR on innovation, we find no statistically significant effects.

Table 5 Results of fixed-effect DiD panel estimations on the effect of GDPR on innovation output (model variant 2)

	Innovation yes/no (all firms)			Innovation output share (only firms with the respective type of innovation)		
	IN_F	*IN_M*	*IN_C*	*INS_F*	*INS_M*	*INS_C*
	(1)	(2)	(3)	(4)	(5)	(6)
GDPR_OB	0.046***	-0.012	0.045***	0.010	0.012	-0.011
	(0.014)	(0.009)	(0.011)	(0.013)	(0.017)	(0.008)
GDPR_SU	0.127***	-0.005	0.066**	0.014	-0.049*	-0.044**
	(0.037)	(0.024)	(0.027)	(0.025)	(0.028)	(0.020)
ININP	0.536	1.662***	1.418***	-0.504	0.648	0.114
	(0.705)	(0.628)	(0.470)	(0.530)	(0.639)	(0.501)
RDSH	1.899***	0.659*	0.673*	0.416	0.366	0.529***
	(0.447)	(0.353)	(0.367)	(0.364)	(0.517)	(0.190)
DIG	0.615	-1.500	2.906*	0.618	-2.190	-2.037*
	(2.115)	(1.748)	(1.621)	(1.790)	(2.364)	(1.210)
EXP	-0.043	-0.006	0.018	0.041	-0.006	-0.019
	(0.033)	(0.025)	(0.025)	(0.029)	(0.037)	(0.023)
EMP	0.035***	0.013**	0.012*	-0.006	-0.017	0.005
	(0.010)	(0.006)	(0.007)	(0.013)	(0.026)	(0.009)
AGE	-0.001	-0.010	-0.002	-0.031	-0.058**	-0.023*
	(0.019)	(0.013)	(0.013)	(0.026)	(0.028)	(0.014)
HC	0.048**	-0.009	-0.012	0.009	-0.011	-0.001
	(0.023)	(0.016)	(0.016)	(0.028)	(0.043)	(0.020)
Constant	0.133*	0.084*	0.093*	0.324***	0.403***	0.147***
	(0.072)	(0.048)	(0.050)	(0.101)	(0.141)	(0.056)
No. observations	28,761	28,761	28,804	7,026	3,053	3,107
No. firms	6,349	6,349	6,363	3,050	1,361	1,671
R-squared	0.019	0.008	0.014	0.005	0.020	0.065
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes

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

Split models

For analysing likely differences in the innovation effects of the GDPR, we run split models by firm size, firm age and different sector groupings. Full estimation results of split models are reported in Table7 to Table 1 in the Appendix. The results for our key variables of interest, *GDPR_OB* and *GDPR_SU*, are summarised in Table 6. The split models reveal that the main finding from the base model −a positive effect of GDPR on incremental innovation and a negative one on radical innovation− tends to occur in different groups of firms. When looking at the group of firms that report that the GDPR complicated their innovation activities (columns 1 to 3), the higher sales from incremental innovations primarily arise among medium-sized firms and old firms while the negative effects on radical innovation are strongest among small firms and young firms. With respect to sectors, our main findings refer to firms from knowledge-intensive industries and firms in B2B industries. For process innovation output, we find positive effects on cost reduction for medium-sized and medium-aged firms as well as for firms in service industries.

Table 6 Results of fixed-effect DiD panel estimations on the effect of GDPR on innovation output for split models (model variant 1)

Split model	*GDPR_OB* *INS_F* (1)	*INS_M* (2)	*INS_C* (3)	*GDPR_SU* *INS_F* (4)	*INS_M* (5)	*INS_C* (6)	No. of observ.[a]
<20 employees	0.007	-0.009**	0.002	0.043**	-0.024	-0.008	14,012
	(0.007)	(0.004)	(0.002)	(0.019)	(0.016)	(0.010)	[3,188]
20-99 employees	0.015*	-0.002	0.005**	0.026	-0.016*	-0.001	9,764
	(0.008)	(0.004)	(0.002)	(0.022)	(0.010)	(0.003)	[2,059]
100+ employees	0.002	-0.004	-0.004	0.020	0.006	0.004	4,985
	(0.009)	(0.005)	(0.003)	(0.032)	(0.007)	(0.008)	[1,102]
<16 years	0.017	-0.023***	0.000	0.069***	-0.041	-0.014	7,284
	(0.011)	(0.007)	(0.003)	(0.024)	(0.028)	(0.015)	[1,853]
16-30 years	-0.003	-0.001	0.004**	0.024	-0.010	0.005	13,136
	(0.007)	(0.003)	(0.002)	(0.022)	(0.008)	(0.006)	[2,833]
>30 years	0.023***	0.002	0.001	0.012	0.001	-0.007*	8,341
	(0.007)	(0.004)	(0.002)	(0.021)	(0.005)	(0.004)	[1,663]
B2B industries	0.014**	-0.007*	0.003	0.029	-0.025*	-0.004	16,711
	(0.006)	(0.004)	(0.002)	(0.021)	(0.015)	(0.006)	[3,721]
B2C industries	0.003	-0.003	0.001	0.036**	-0.005	-0.002	12,050
	(0.007)	(0.003)	(0.002)	(0.016)	(0.006)	(0.008)	[2,628]
Manufacturing	0.008	-0.007*	-0.000	0.024	-0.007	-0.002	13,151
	(0.007)	(0.004)	(0.002)	(0.022)	(0.009)	(0.004)	[2,893]
Services	0.008	-0.005	0.004**	0.036**	-0.021	-0.004	15,610
	(0.006)	(0.004)	(0.002)	(0.016)	(0.013)	(0.008)	[3,456]
Knowledge-intensive	0.016**	-0.012**	0.002	0.037*	-0.028*	-0.003	11,946
Industries	(0.008)	(0.005)	(0.002)	(0.021)	(0.015)	(0.008)	[2,666]
Not knowledge-intensive	0.005	0.001	0.002	0.031**	0.000	-0.004	16,815
industries	(0.005)	(0.002)	(0.002)	(0.015)	(0.004)	(0.006)	[3,683]

Robust standard errors in parentheses, * p<0.1, ** p<0.05, *** p<0.01.
a: Number of observations for *INS_F* and *INS_M* (number of observations for *INS_C* differ slightly), number of firms in squared brackets.

The results for the group of firms that report that the GDPR has facilitated their innovation activities (columns 4 to 6) demonstrated that the positive effects on sales with incremental product innovations are confined to small and young firms as well as firms from B2C industries and services. With respect to the knowledge-intensity of the industry, the positive effects are found for both types. The negative effects on sales with new-to-market innovations primarily appear among small firms (though only very weakly significant) and medium-sized firms as well as in B2B industries and knowledge-intensive industries.

6. Discussion

The introduction of the GDPR in 2018 resulted at first glance in a shift of innovation activities in firms affected by the GDPR towards more incremental innovation and away from radical innovation. This holds for both firms that report that the GDPR was an obstacle to their innovation efforts, and for the much smaller group of firms that report that the GDPR facilitated innovation. The former group increased their sales share with product innovation that were only new to the firm by 0.9 percentage points while the sales share of new-to-market products fell by 0.6 percentage points. For the latter group, the effects are more substantial, with an increase of the sales share of incremental innovations by 3.3 percentage points, contrasted by a fall of radical product innovation by 1.5 percentage points. In terms of process innovation output, the GDPR encouraged more firms to introduce new or improved processes that reduced cost, though the share of unit cost reduction was smaller than for process innovators not affected by the GDPR.

The results for different groups of firms reveal that small firms and young firms primarily experienced lower innovation output in terms of radical innovation, while innovation output for incremental innovation was only positively affected for the small group of firms reporting that the GDPR facilitated innovation. In contrast, older firms show strong positive effects from the GDPR on incremental innovation but no significant negative effects on radical innovation. Heterogeneity in terms of GDPR effects is also found for firms from different sectors. The general finding of positive effects on incremental and negative ones on radical innovation is mainly limited to B2B industries and knowledge-intensive industries. Manufacturing firms tend to experience more negative than positive effects. The opposite is found for service firms.

What this data shows us is the following. Firstly, the impact of the GDPR - regardless as to whether respondents stated it to be an obstacle or stimulating innovation - was never fully negative. This stands in contrast to outcries outlining the inherent negative effect of the GDPR on the economy and innovation (see Wallace and Castro 2018). At first glance, though it did not seem to have positive effect on the share of sales from radical innovation, it did have positive effect on innovation nonetheless, in the form of incremental innovation. Considering that the GDPR is unchartered territory in terms of not only being the most comprehensive data protection regulation to date, but also a trailblazer as arguably the first ambitious regulation specifically targeted at regulating the digital economy, these findings make sense. A lack of precedence and information means that most likely incremental innovation in ensuring compliance would be initially a more attractive option. As time progress and information about the GDPR increase as well as vital court cases shedding further light on key stipulations and the parameters of the GDPR, would provide the sure footing that makes radical innovation more attractive and less risky.

These findings are highly interesting and can be explained when considering the target group of the GDPR and who it affects most significantly. Those companies most threatened by the

GDPR whether it be compromising their traditional revenue model (e.g. daten-driven business models) or whether it forces them to restructure (e.g. need to increase cybersecurity mechanisms for data breaches) will be those that most likely will see the GDPR as an obstacle. Hence, these companies are currently incentivized by the GDPR to innovate incrementally to achieve compliance. However, those companies who stated that the GDPR would stimulate innovation are companies who do not feel threatened by it. These companies are more than likely either hardly involved in the digital economy (e.g. traditional industries) whose involvement with consumer data is limited (e.g. contact details for a newsletter) or those few companies that are themselves already in the business of privacy protection or even cybersecurity. The former group has limited risk as it collects and processes very little consumer data and the latter, is more than likely to be already compliant and if not chances are that only small changes would be required. Consequently, both groups could simply acquire a template and adapt to their own circumstances explaining the results of positive effect with regards to sales share of incremental innovation and a negative one regarding the radical innovation. When focusing on the firms reporting that the GDPR complicated their innovation activities, we observe that the higher sales from incremental innovations primarily experienced by medium-sized firms and old firms while the negative effects on radical innovation are strongest among small firms and young firms. However, among the firms reporting that the GDPR has facilitated their innovation activities, in particular small and young firms experience positive effects on sales with incremental product innovations.

Our study faces several limitations. First, our empirical study is based on of German companies, which challenges the transferability of our findings to other European companies. Due to the data protection sensitive culture within Germany (see Bygrave 2010), the answers of the firms might be biased towards perceiving the GDPR more as an obstacle rather than as a beneficial, which has important implications for our findings. Furthermore, the questionnaire did not explicitly mention the GDPR, but only data protection in general, which might lead to a too strong attribution of the responses to the GDPR. Unfortunately, this lack of clarity cannot be solved by follow-up interviews with the respondents. Finally, it has to be pointed out that the survey data allows one to make conclusion for the short-term impacts of the GDPR. Medium or even long term impacts can be only measured in coming years. Therefore, our results offer only a preliminary snapshot. This has important implications in particular for the distinction between incremental and radical innovation, which might be realised only in later years. Furthermore, firms might adjust further their innovation strategies specifically to the requirements and opportunities of the GDPR, which is not considered in the data we rely on. In summary, a replication of our analysis in a few years is required based on more GDPR-specific data.

7. Conclusions

This paper assessed the impacts of the EU's General Data Protection Regulation (GDPR) that was introduced in 2018 on innovation activities in firms, using novel data from the German part of the Community Innovation Survey (CIS). Based on a difference-in-difference analyses using panel data of the German innovation survey, we reveal that the GDPR caused a shift of innovation activities in firms affected by this new data protection regulation leading to more incremental and less radical innovation. This holds for both firms that perceive that the GDPR was an obstacle to their innovation efforts, and for the much smaller group of firms that report that the GDPR supported their innovation activities and successes.

The former group increased their sales share with product innovation that were only new to the firm by 0.9 percentage points while the sales share of new-to-market products fell by 0.6 percentage points. The latter group experienced much stronger impacts of the GDPR on their innovative sales. The sales share of only new-to-firm product innovation increased by 3.3 percentage points, and the sales share of new-to-market products fell by 1.5 percentage points.

We interpret these results as follows: The GDPR forced firms to adapt their existing products and services in order to comply with the GDPR. Some firms used this opportunity to also make innovative changes to their products and services. These changes were rather marginal, however. They resulted in improvements or updates to align products and services to those of competitors. These effects differed by the way the GDPR affected a firm:

In case the GDPR represented a stimulus for innovation (which applies to less than 5% of the affected firms), the shift towards incremental innovation was particularly strong. Additional innovation efforts of this group of firms deliberately targeted incremental improvements. This may be linked to the fact that uncertainty about the consequences of the GDPR was high both for innovators and for the users of new products and services for which the GDPR was relevant. Firms hence opted for the safe way and updated or improved their products or services to both meet GDPR requirements and offer some additional features for users. Another additional point could be that under a lower threat of enforcement under the previous data protection regime (see Martin et al. 2019) there was less incentive to comply and adopt basic privacy features, whereas under the GDPR there was more incentive to comply as a result of the significant fines. Hence, companies became more up-to-date regarding privacy features that was already in existence but had simply not been adopted. The sector distribution of firms that report an innovation facilitating impact of the GDPR suggest that many of these innovations represent solutions for the firms' customers to comply with the GDPR, e.g. updated software programmes. Finally, larger and older firms experience stronger increases of innovations that are new to the firm, whereas small and young firms benefit less.

Our findings have significant policy implications, as claims regarding the particularly negative effects of the GDPR on SMEs has been one of the major arguments criticising the GDPR and its impact on innovation. Moreover, it has also implications for competition concerns where despite the GDPR also aiming to promote competition, claims of the disproportionate burden on SMEs has been argued to entrench the dominance of the large tech companies. Since small and young companies experiencing hindering impacts from the GDPR have both less increases in sales from incremental innovations and more negative effects on their turnovers with radical innovation, their compliance with the GDPR has to be facilitated further by specifically shaped programmes. In parallel, very small and young companies, which report GDPR facilitating innovation, experience significant increases in turnover with radical innovations. Obviously, the GDPR provides opportunities for start-ups to develop new markets (Martin et al. 2019). Consequently, entrepreneurship programmes could consider the GDPR as option and not necessarily as a barrier for start-ups. Finally, policies related to knowledge intensive sectors might exploit the potential of the GDPR as a cross-sectoral regulation.

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9. Appendix

Table7 Results of fixed-effect DiD panel estimations on the effect of GDPR on innovation output: split models by size (model variant 1)

	<20 employees			20-99 employees			100+ employees		
	INS_F	*INS_M*	*INS_C*	*INS_F*	*INS_M*	*INS_C*	*INS_F*	*INS_M*	*INS_C*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
GDPR_OB	0.007	-0.009**	0.002	0.015*	-0.002	0.005**	0.002	-0.004	-0.004
	(0.007)	(0.004)	(0.002)	(0.008)	(0.004)	(0.002)	(0.009)	(0.005)	(0.003)
GDPR_SU	0.043**	-0.024	-0.008	0.026	-0.016*	-0.001	0.020	0.006	0.004
	(0.019)	(0.016)	(0.010)	(0.022)	(0.010)	(0.003)	(0.032)	(0.007)	(0.008)
RDINP	-0.424	0.213	-0.076	-0.486	0.494	0.213*	0.241	0.173	0.120
	(0.442)	(0.370)	(0.121)	(0.565)	(0.678)	(0.126)	(0.722)	(0.250)	(0.142)
NRDINP	0.331	0.111	0.091	0.551*	0.266	0.211**	1.502***	-0.018	0.220*
	(0.250)	(0.214)	(0.094)	(0.289)	(0.287)	(0.098)	(0.574)	(0.417)	(0.132)
DIG	1.053	-0.806	0.227	-0.662	-1.145	0.147	2.888*	-0.259	-0.035
	(1.493)	(0.929)	(0.525)	(1.642)	(0.748)	(0.266)	(1.482)	(0.544)	(0.277)
EXP	-0.003	0.007	-0.003	0.000	-0.014	0.000	-0.002	-0.017	-0.008
	(0.024)	(0.019)	(0.006)	(0.019)	(0.014)	(0.004)	(0.015)	(0.018)	(0.005)
EMP	0.005	0.003	0.001	0.007	-0.003	0.002	0.014**	-0.002	0.001
	(0.005)	(0.003)	(0.001)	(0.006)	(0.003)	(0.002)	(0.006)	(0.004)	(0.002)
AGE	-0.005	-0.012	-0.003	-0.002	-0.013**	-0.004*	-0.034	-0.007	0.005*
	(0.010)	(0.008)	(0.003)	(0.012)	(0.005)	(0.002)	(0.022)	(0.008)	(0.003)
HC	0.011	0.001	-0.000	0.010	-0.013	-0.000	0.018	0.023	-0.005
	(0.011)	(0.005)	(0.003)	(0.017)	(0.010)	(0.005)	(0.025)	(0.015)	(0.007)
Constant	0.065*	0.050**	0.018*	0.032	0.070***	0.015	0.086	0.050	-0.005
	(0.035)	(0.025)	(0.011)	(0.051)	(0.023)	(0.011)	(0.086)	(0.035)	(0.014)
No. observ.	14,012	14,012	14,115	9,764	9,764	9,757	4,985	4,985	4,932
No. firms	3,188	3,188	3,201	2,059	2,059	2,063	1,102	1,102	1,099
R-squared	0.010	0.007	0.005	0.008	0.008	0.009	0.020	0.008	0.007
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

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

Table 8 Results of fixed-effect DiD panel estimations on the effect of GDPR on innovation output: split models by age (model variant 1)

	<16 years			16-35 years			>35 years		
	INS_F (1)	*INS_M* (2)	*INS_C* (3)	*INS_F* (4)	*INS_M* (5)	*INS_C* (6)	*INS_F* (7)	*INS_M* (8)	*INS_C* (9)
GDPR_OB	0.017	-0.023***	0.000	-0.003	-0.001	0.004**	0.023***	0.002	0.001
	(0.011)	(0.007)	(0.003)	(0.007)	(0.003)	(0.002)	(0.007)	(0.004)	(0.002)
GDPR_SU	0.069***	-0.041	-0.014	0.024	-0.010	0.005	0.012	0.001	-0.007*
	(0.024)	(0.028)	(0.015)	(0.022)	(0.008)	(0.006)	(0.021)	(0.005)	(0.004)
RDINP	-0.491	-0.300	0.103	-0.322	0.715**	-0.027	-0.150	0.651	-0.014
	(0.546)	(0.547)	(0.150)	(0.513)	(0.322)	(0.125)	(0.484)	(0.645)	(0.120)
NRDINP	0.078	0.370	0.197	0.864***	0.114	0.084	0.482**	0.032	0.192**
	(0.376)	(0.378)	(0.144)	(0.329)	(0.161)	(0.086)	(0.217)	(0.308)	(0.096)
DIG	0.761	-1.507	-0.621	0.750	-0.372	0.603**	1.375	-0.325	0.149
	(1.995)	(1.307)	(0.709)	(1.180)	(0.643)	(0.241)	(1.912)	(0.494)	(0.499)
EXP	0.003	-0.003	-0.002	-0.006	-0.018	-0.006	0.001	0.006	0.000
	(0.029)	(0.024)	(0.007)	(0.019)	(0.016)	(0.005)	(0.015)	(0.009)	(0.005)
EMP	-0.002	0.002	0.001	0.013***	-0.002	0.001	0.007	0.003	0.003
	(0.007)	(0.004)	(0.001)	(0.005)	(0.002)	(0.001)	(0.005)	(0.002)	(0.002)
AGE	-0.002	-0.001	-0.000	0.008	-0.046	-0.007	-0.169**	0.018	0.027
	(0.011)	(0.006)	(0.002)	(0.065)	(0.029)	(0.020)	(0.068)	(0.039)	(0.018)
HC	0.035*	-0.005	0.005	0.005	-0.002	-0.005	-0.005	0.011	-0.000
	(0.020)	(0.010)	(0.005)	(0.010)	(0.006)	(0.004)	(0.013)	(0.007)	(0.004)
Constant	0.065*	0.030	0.011	-0.006	0.171*	0.030	0.710***	-0.078	-0.111
	(0.038)	(0.018)	(0.008)	(0.212)	(0.095)	(0.064)	(0.275)	(0.159)	(0.075)
No. observat.	7,284	7,284	7,323	13,136	13,136	13,164	8,341	8,341	8,317
No. firms	1,853	1,853	1,863	2,833	2,833	2,838	1,663	1,663	1,662
R-squared	0.012	0.014	0.007	0.010	0.009	0.007	0.011	0.008	0.005
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

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

Table 9 Results of fixed-effect DiD panel estimations on the effect of GDPR on innovation output: split models by B2B and B2C industry (model variant 1)

	B2B industries			B2C industries		
	INS_F	*INS_M*	*INS_C*	*INS_F*	*INS_M*	*INS_C*
	(1)	(2)	(3)	(4)	(5)	(6)
GDPR_OB	0.014**	-0.007*	0.003	0.003	-0.003	0.001
	(0.006)	(0.004)	(0.002)	(0.007)	(0.003)	(0.002)
GDPR_SU	0.029	-0.025*	-0.004	0.036**	-0.005	-0.002
	(0.021)	(0.015)	(0.006)	(0.016)	(0.006)	(0.008)
RDINP	-0.213	0.379	0.055	-1.160*	-0.119	-0.122
	(0.364)	(0.335)	(0.083)	(0.691)	(0.585)	(0.284)
NRDINP	0.489**	0.041	0.084	0.555**	0.411	0.300*
	(0.232)	(0.184)	(0.057)	(0.281)	(0.318)	(0.155)
DIG	2.056	-1.256	0.174	-0.640	-0.194	0.079
	(1.345)	(0.865)	(0.365)	(1.258)	(0.424)	(0.397)
EXP	0.001	0.001	-0.000	-0.011	-0.025	-0.010
	(0.014)	(0.011)	(0.003)	(0.028)	(0.023)	(0.008)
EMP	0.011**	0.000	0.001	0.002	-0.000	0.001
	(0.005)	(0.003)	(0.001)	(0.004)	(0.002)	(0.001)
AGE	-0.011	-0.013*	-0.002	-0.003	-0.010*	-0.002
	(0.010)	(0.007)	(0.002)	(0.011)	(0.005)	(0.002)
HC	0.008	-0.001	0.000	0.019	-0.003	-0.002
	(0.011)	(0.007)	(0.004)	(0.013)	(0.006)	(0.003)
Constant	0.056	0.064***	0.014	0.055	0.043**	0.013
	(0.038)	(0.024)	(0.009)	(0.042)	(0.019)	(0.010)
No. observations	16,711	16,711	16,784	12,050	12,050	12,020
No. firms	3,721	3,721	3,732	2,628	2,628	2,631
R-squared	0.009	0.007	0.004	0.009	0.008	0.006
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes

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

Table 10 Results of fixed-effect DiD panel estimations on the effect of GDPR on innovation output: split models by manufacturing and services (model variant 1)

	Manufacturing			Services		
	INS_F (1)	*INS_M* (2)	*INS_C* (3)	*INS_F* (4)	*INS_M* (5)	*INS_C* (6)
GDPR_OB	0.008	-0.007*	-0.000	0.008	-0.005	0.004**
	(0.007)	(0.004)	(0.002)	(0.006)	(0.004)	(0.002)
GDPR_SU	0.024	-0.007	-0.002	0.036**	-0.021	-0.004
	(0.022)	(0.009)	(0.004)	(0.016)	(0.013)	(0.008)
RDINP	-0.786*	0.195	0.116	0.002	0.335	-0.065
	(0.414)	(0.373)	(0.127)	(0.479)	(0.445)	(0.113)
NRDINP	0.802***	0.001	0.131*	0.204	0.311	0.173*
	(0.273)	(0.159)	(0.076)	(0.235)	(0.290)	(0.100)
DIG	-0.240	-1.505	1.057***	1.223	-0.522	-0.273
	(1.562)	(1.505)	(0.341)	(1.142)	(0.371)	(0.351)
EXP	-0.017	-0.010	-0.005	0.027	0.000	0.000
	(0.017)	(0.014)	(0.004)	(0.018)	(0.014)	(0.005)
EMP	0.006	0.002	0.001	0.008**	-0.001	0.001
	(0.006)	(0.003)	(0.002)	(0.004)	(0.002)	(0.001)
AGE	-0.015	-0.013**	-0.002	-0.005	-0.012	-0.003
	(0.010)	(0.005)	(0.002)	(0.011)	(0.007)	(0.003)
HC	0.016	0.010	0.001	0.011	-0.006	-0.002
	(0.019)	(0.009)	(0.005)	(0.009)	(0.005)	(0.003)
Constant	0.086**	0.057***	0.015	0.046	0.054**	0.013
	(0.043)	(0.020)	(0.010)	(0.040)	(0.025)	(0.010)
No. observations	13,151	13,151	13,256	15,610	15,610	15,548
No. firms	2,893	2,893	2,900	3,456	3,456	3,463
R-squared	0.012	0.009	0.005	0.011	0.006	0.006
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes

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

Table 11 Results of fixed-effect DiD panel estimations on the effect of GDPR on innovation output: split models by knowledge intensity of industries (model variant 1)

	Knowledge-intensive industries			Not knowledge-intensive industries		
	INS_F	*INS_M*	*INS_C*	*INS_F*	*INS_M*	*INS_C*
	(1)	(2)	(3)	(4)	(5)	(6)
GDPR_OB	0.016**	-0.012**	0.002	0.005	0.001	0.002
	(0.008)	(0.005)	(0.002)	(0.005)	(0.002)	(0.002)
GDPR_SU	0.037*	-0.028*	-0.003	0.031**	0.000	-0.004
	(0.021)	(0.015)	(0.008)	(0.015)	(0.004)	(0.006)
RDINP	-0.522	0.360	0.017	0.640	0.300	0.015
	(0.360)	(0.329)	(0.092)	(0.664)	(0.479)	(0.206)
NRDINP	0.550*	-0.046	0.153	0.468**	0.298*	0.145**
	(0.332)	(0.325)	(0.113)	(0.202)	(0.158)	(0.071)
DIG	0.244	-0.853	0.110	2.601*	-0.214	0.184
	(1.179)	(0.720)	(0.321)	(1.509)	(0.475)	(0.510)
EXP	0.008	-0.005	0.000	-0.009	-0.007	-0.006**
	(0.022)	(0.018)	(0.005)	(0.012)	(0.007)	(0.003)
EMP	0.004	-0.000	0.001	0.009**	0.000	0.002*
	(0.006)	(0.004)	(0.002)	(0.004)	(0.002)	(0.001)
AGE	-0.002	-0.024**	-0.001	-0.010	-0.001	-0.003
	(0.013)	(0.010)	(0.003)	(0.009)	(0.002)	(0.002)
HC	0.019	-0.001	-0.003	0.003	0.001	0.002
	(0.012)	(0.007)	(0.004)	(0.011)	(0.004)	(0.003)
Constant	0.071	0.109***	0.016	0.037	0.008	0.010
	(0.049)	(0.034)	(0.012)	(0.034)	(0.009)	(0.008)
No. observations	11,946	11,946	12,120	16,815	16,815	16,684
No. firms	2,666	2,666	2,677	3,683	3,683	3,686
R-squared	0.012	0.011	0.005	0.009	0.005	0.005
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes

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

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