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Is it all the same? Types of innovation and their relationship with direct control, technical control and algorithmic management across European firms.

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Is it all the same? Types of innovation and their relationship with direct control, technical control and algorithmic management across European firms

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Abstract

Using firm-level data from 28 European countries, this paper explores the relationship between two types of innovation (process and digital) and different forms of control (direct and indirect) at the workplace. We find that (1) digital innovation is more common than process innovation; (2) more innovative firms record higher levels of indirect control (especially related to algorithmic management) and lower level of direct control (3) the relationship between innovation and control is not uniform across European countries. These findings nurture the debate on the future of work as the process of digitalisation may promote a shift towards indirect forms of control and contribute to reduce the degree of direct control. Moreover, these changes may also affect the bargaining process and lead to a redefinition of managerial roles, though it should be acknowledged that social and institutional factors play an important role in shaping this process.

Keywords: Process innovation; Digital innovation; Algorithmic management; Control, European firms.

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Executive Summary

The economic literature has always paid attention to the relationship between innovation and other spheres of work and the economy, such as employment, productivity and growth. In addition to these topics, the growing debate on the changing nature of work also embraces how innovation interacts and impacts on work organisation of the firms. Within this context, work organisation and working conditions (e.g. forms of control, work intensity, work-life balance) are all relevant areas of research. The relationship between innovation and work organisation has always been important and it is becoming even more critical with the advent of new vectors of technological change, such as automation and digitalization. The importance and pervasiveness of these changes are peculiar of the current technological wave whose potential, especially in terms of data collection and processing, is exponential. It is therefore pivotal to investigate old questions with new realities.

The paper aims at contributing precisely to this strand of literature and addresses the following research questions. What is the relationship between different types of innovation and, direct and indirect control? Are there relevant differences between process and digital innovations in the way they link to different forms of control? Are there significant differences across European regions or the relationship is uniform?

Answering these questions is relevant for different reasons. To the best of our knowledge, while some researches investigate the link between innovation and work organisation at the country or company level (see next section), cross-country studies are very scarce. Moreover, the evidence concerning the use of algorithmic management is still scant. Most of the existing literature interested in this topic usually deals with case studies and/or is delimited to a subset of industries (usually related to platform workers, e.g. Mateescu & Nguyen 2019; Wood 2021). This paper represents a step forward in this respect as we use a representative dataset of European firms which cover the whole spectrum of industries and provides a comprehensive picture of different ways of control of the workforce.

From a policy perspective, this study contributes to the discussion on the future of work. Our evidence show that there exists a strict relationship between the adoption of digital tools and the deployment of algorithmic management. More generally, we find that there is a qualitative shift in the forms of control that workers are subject to, from direct control to indirect ones. This indicates that while there may be similar tendencies that emerge once an innovation takes place, institutional characteristics can have an important role in shaping the impact of technology on work organisations. Finally, the results suggest that the level of direct control may reduce in favour of indirect control (mediated by machines and algorithms), which poses questions on the possible evolutions of managerial roles.

1 Introduction

Several studies investigate the link between innovation and other spheres of work and the economy, such as employment, (Dachs et al., 2017; Piva and Vivarelli, 2005), productivity (Hall, 2011; Mohnen and Hall, 2013) and growth (Demirel & Mazzucato, 2012). In addition to these topics, the growing debate on the changing nature of work also embraces how innovation interacts and impacts on work organisation of the firms. Within this context, work organisation and working conditions (e.g. forms of control, work intensity, work-life balance) are all relevant areas of research. This paper contributes to these strands by focusing on the link between innovation and a specific dimension of work organisation, that is control, using data from the European Company Survey which provides establishment-level information for 28 European countries.

The relationship between innovation and work organisation has always been important and it is becoming even more critical, as new technologies are rapidly changing the way people work. In this respect, one novelty of this paper is that it explores the relationship between innovation and forms of control focusing on the role played by two types of innovation, process innovation and digital innovation. While process innovation generally refers to the introduction of a new or improved process of production that differs from those previously in use (OECD/Eurostat, 2018), digital innovation narrows the perspective, referring specifically to the introduction of digital software and devices in the production process.

At the same time, it should be acknowledged that also the type of control that workers are subject to can be multiform. Drawing from Edwards (1982), we distinguish between direct control, which is applied and exerted directly by managers and supervisors, and indirect forms of control which are mediated by machines, computers, and other digital devices. The distinction between different types of control is becoming increasingly pivotal in our times. Indirect control includes the deployment of digital surveillance by means of data analytics to monitor employees. This points to the application of algorithmic management which consists in the use of computer-programmed procedures for the coordination of labour input (Baiocco et al., 2022). As digitalisation increases the amount and expands the domain of data collected and at the same time boosts the computing power to process it, it fosters the possibility of introducing algorithmic management of the workforce. It immediately follows that digitalisation is at the core of the debate on the future of work as it has a pervasive impact along several dimensions of the labour process (Berger & Frey 2016; Wood 2021).

In light of these elements, it becomes evident the importance of assessing the relationship between the introduction of different types of innovation and the way work is performed. Specifically, the paper addresses the following research questions. What is the relationship between different types of innovation and, direct and indirect control? Are there relevant differences between process and digital innovations in the way they link to different forms of control? Are there significant differences across European regions or the relationship is uniform?

Answering these questions is relevant for different reasons. To the best of our knowledge, while some researches investigate the link between innovation and work organisation at the country or company level (see next section), cross-country studies are very scarce. Moreover, the evidence concerning the use of algorithmic management is still scant. Most of the existing literature interested in this topic usually deals with case studies and/or is delimited to a subset of industries (usually related to platform workers, e.g. Mateescu & Nguyen 2019; Wood 2021). This paper represents a step forward in this respect as we use a representative dataset of European firms which cover the whole spectrum of industries and provides a comprehensive picture of different ways of control of the workforce.

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The rest of the paper is structured as follows. Section 2 summarises the relevant academic literature on the effect of process and digital innovation on work organisation with a special focus on different forms of control. Section 3 presents the data used for the quantitative analysis and section 4 provides descriptive evidence on the relationship between process and digital innovation and control (direct and indirect). Here, the preliminary evidence shows that innovation is associated with a higher level of indirect control, and lower levels of formal control. This link is investigated econometrically in section 5 while section 6 discusses the main results and their relevance for policy.

2 Innovation and work organisation. An overview of the relevant literature

The introduction of innovations has always accompanied changes in the way humans perform their work. The examples in this respect are countless. The invention of the wheel implied the reduction of strength that humans needed to employ in their work, the first industrial revolution and the capitalist mode of production led to the substitution of skilled labour for unskilled labour and increase in the repetitiveness of work, digital tools allow to increase the flexibility of rhythms of work, etc.

Different authors have tried to establish a possible link between innovation and the changes in the production process. One of the first scholars to focus explicitly on this topic was Braverman (1974), who argued that the introduction of machines contributed significantly to the intensification of the forms of control and command over the workforce, especially in those contexts with lower workers' involvements in the decision process.

The relationship between innovation and work organization has become even more important recently with the advent of new vectors of technological change, such as automation and digitalization. It is not easy to identify uniquely the features of new technologies. Eurofound (2018) traces four main aspects that characterise the era of digitalization of the economy: (1) flexibility of production, which is possible thanks to the use of algorithms that can be recalibrated in a relatively quick time; (2) availability of information, that permits to reduce transaction costs facilitates complex operations and increases the possibility of outsourcing specific tasks; (3) zero or low marginal costs, which enable some firms to expand their output at very low costs; (4) network effects, which are likely to lead to increasing returns and higher market concentration. Ultimately, digitalisation can be understood as the use of digital data and technology to automate data handling and optimize processes (Buer et al., 2018).

While some of these features were common also to previous technological waves, the importance and pervasiveness of these characteristics are peculiar of the current technological wave whose potential, especially in terms of data collection and processing, is exponential. For this reason, it is understandable that the rise of new technologies and their relationship to work organisation is attracting growing attention. In this respect, it is possible to distinguish at least two contrasting views. Some authors stress the benefits that new technologies would bring to the working conditions. Brynjolfsson and McAfee (2014, p. 166) claim that, despite in the short run there may be considerable challenges in the labour markets, digital technologies will lead to "less need to work doing boring, repetitive tasks and more opportunity for creative and interactive work". Analogously, Kaasinen et al. (2020) maintain that Industry4.0 will bring higher autonomy to the workforce and according to Becker and Stern (2004) computerisation and automation will be accompanied by a reduction in repetitive tasks in favour of complex and advanced ones. Focusing on the health sector, Leso et al. (2018, p. 331) argue that workers in the fourth industrial revolution we will witness the disappearance of "routine tasks and [we will] achieve a greater autonomy and self-development". Other scholars maintain that the process of digitalisation of the production process can have even broader benefits and, for example, could help to improve workers' psychological health and wellbeing (Carpanzano et al., 2018).

Other authors have a less optimistic view of the impact of new technologies on work activities. Edwards (1982), who was a pioneer in the study of the relationship between digital technologies and forms of control, holds that the introduction of digitally-enabled machines is not neutral and is bound to the reduction of workers' autonomy. Digital technologies promote a shift from direct forms of control (operated by managers and supervisors) to indirect forms of control in which the functions of managers are mediated by machines, digital devices and algorithms that determine the pace and control of the workers and their activities. As we shall see below, this distinction is especially valid for our times (and our study). It could be argued that with the rise of digitalisation, the role of technical control and algorithmic management to monitor employees' performance may increase in importance and pervasiveness relative to direct control, modifying the traditional relations of authority at the workplace.

Another group of scholars has highlighted how the process of digitalisation may foster the standardisation of tasks performed by workers. Digital-enabled machines have the capacity of acquiring information and workers' knowledge on specific tasks (like the ability to solve problems as they emerge during a production phase). Computers codify and store tacit knowledge, incorporating it into instructions and procedures to be followed once similar events occur. The possibility to codify analytical tasks into simple procedures fosters workers' repetitiveness and standardisation. In this respect, using data from different waves of the European Working Condition survey, Bisello et al. (2019) find that the increase in computerization at the job level has a positive impact on the degree of standardisation. Notably, this finding holds not only between different types of jobs, but also within the same job. Butollo et al. (2019) focuses on the effects of data-based process management, digital assistance systems, and other Industry4.0 applications and find that the deployment of digital technologies increases the degree of standardisation and operates a reduction the experiential knowledge of workers which is now substituted by knowledge embodied into data-based process systems and techniques. Along these lines, Delfanti's (2021) study of an Italian Amazon warehouse highlights that algorithmic direction dispossesses workers of the knowledge that would otherwise be necessary to carry out the job and make their operations more repetitive, while Green et al. (2021) have recently found that in the UK organisational innovation has led to an increase in work intensity.

The possibility to introduce new forms of control using digitally enabled machines has been important in the decision to grant remote work to employees. Felstead and co-authors (2003) investigate the extent to which new technological devices have been introduced to replicate visibility and direct control showing that this was the case mostly for more technologically sophisticated organisations, like telecommunication. Taskin and Edwards (2007) address the question of the impact of telework on workers' autonomy and control focusing on the public sector in Belgium. According to their findings, telework enables supervision and managerial control over workers by superimposing new practices to old and more traditional ones. Managerial control is reinforced by performance management techniques fostering performance-based work and individualisation. Similar results have been found in recent qualitative studies on the effect of the massive shift towards telework induced by the Covid-19 crisis (Fana et al., 2021).

Other authors have focused on the uneven impact of innovation among workers of the same firm. Marler and Liang (2012) show that the adoption of enterprise-wide information technology systems can impact differently the occupational hierarchy: workers in clerical jobs compared to technical and managerial jobs. Along these lines, Gerten et al. (2018) using matched employer-employee data for Germany find that the diffusion of Information and Communication Technologies (ICT) at the workplace level increases autonomy only for employees with a managerial role, while the same does not apply to other employees.

It should also be acknowledged that the existence of distinct institutional factors across countries may lead to differences in the way innovations impact the work organisation. In this sense, a notable case is the so-called Nordic model, which is characterised by high levels of autonomy and participation of the workforce in the decisional process (Rolfsen, 2013). In this context, Ingvalsden et al. (2013) illustrate the high degree of cooperation between workers and supervisors that accompany all stages of production and the introduction of innovations. Therefore, it is possible that the impact of innovations on workers' control and organisation would be different from countries that historically count with lower workers' involvement.

As it can be appreciated, findings on the impact of innovation on work are heterogenous. This picture contrasts with the idea of technological determinism, intended as the tendency of assigning technology (whether hardware or software) the decisive powers to initiate and shape work and broader economic relations" (Thompson & Laaser, 2021, p. 140). In this respect, several authors have highlighted the importance of human agency, social relations and institutions in determining the impact of technology on tasks. This idea was key to the so-called Labour Process Theory, whose proponents argue that technology adoption is not neutral, and their effects cannot be uniquely predetermined (Friedman, 1990). As Noble (1979, pp. 103–104) puts it, "technology is not an autonomous force impinging upon human affairs from the 'outside', but is the product of a social process, a historically specific activity carried on by some people, and not others… In short, technology bears the social 'imprint' of its authors".[1] This perspective could also be applied to the recent rise of algorithmic management where technical tools are implemented to answer preferred/chosen organisational methods (Jarrahi et al., 2021; Kellogg et al., 2020). From this perspective, the way technological progress impacts the organisation of work is the reflection of social processes, mediated by technology.

To resume, the main take-home message of this section is that innovations often are related to changes in the work organisation. The process of digitalisation may intensify these processes qualitatively, introducing new elements into the picture, and quantitatively, accelerating the changes in the work organisation. However, the direction of these changes is not predetermined and may vary considerably in time, across countries or even between and within companies. Moreover, most of the works mentioned above are firm or country-specific. To the best of our knowledge, only few studies cover a cross-country representative sample of firms. These considerations motivate our research and the need to explore the relationship between different types of innovation and forms of control at the workplace.

3 Data

The empirical analysis is performed using data from the latest wave of the European Company Survey (ECS) 2019 conducted jointly by Eurofound and Cedefop. The ECS is carried out on a regular base by Eurofound and it collects data from more than 20,000 establishments with at least 10 employees across 28 European countries. The ECS consists of two different sets of questions that are addressed respectively to firms managers and employee representatives. Given the nature of our investigation, we employ the managers' survey which includes questions that specifically address innovation strategies and work organisation of the firms. We employ the 2019 edition of the ECS because, different from previous editions of the survey, it contains a special focus on the workplace practice, the tasks, and methods of production performed within the firms.

The ECS has been used for a wide range of empirical studies which, among other topics, have dealt with the effects of unionisation on strikes (Jansen, 2014), the relationship between the skill profile of the employees and the provision of flexible working arrangements (Riva et al., 2018), innovation

[1] It is interesting to observe that sometimes technological determinism is used to defend certain managerial policies. As Leonardi and Jackson (2004) show, technological determinism is often used by managers as in their communications to justify and support the "inevitability" of their decisions.

and job quality (Grande et al., 2020) and the relationship between profit-sharing schemes and R&D activities (D'Andria & Uebelmesser, 2021).

As mentioned in the introduction, we employ two different innovation indicators. The first one is process innovation (*innoproc*) which captures whether, since 2016, the company has introduced significant changes in the production process of goods and services. Notice that this definition is close to that provided by the Oslo Manual, which defines process innovation as "a new or improved business process for one or more business functions that differ significantly from the firm's previous business processes and that has been brought into use in the firm" (OECD/Eurostat, 2018).[2] The second indicator, digital innovation (*diginn*), captures whether, since 2016, the firm has introduced any software that was specifically developed or customised to meet the needs of the establishment. As common in this type of studies (Cassetta et al., 2020), both variables are binomial and take values of 1 in case there is innovation and 0 otherwise.

One possible objection may be that digital innovation is a subgroup of process innovation so the former should always be accompanied by the latter. However, the definition of digital innovation employed in this paper does not necessarily imply process innovation. For example, firms can introduce a specific software to monitor the production process without leading to significant changes in the production process of goods and services.

As mentioned in the introduction, our outcome variables identify two different forms of control employees are subjected to, namely direct and indirect control. We employ two indicators of direct control. The first one (*dirctrl1)* measures the extent to which managers define workers' tasks and supervise directly whether employees follow the tasks assigned to them or, on the contrary, managers create an environment in which employees are more autonomous in the organisation of their tasks. The second indicator of direct control (*dirctrl2*) maps the share of employees that independently organise their work and schedule their tasks.

Indirect control instead refers to those forms often mediated by machines, digital tools, algorithms, and monitoring devices which determine the activity of the workers and its pace. We can distinguish between two indicators of indirect control. The first one, technical control (*techctrl*), measures the share of employees whose pace of work is determined by machines or computers. The second indicator, data analytics (*datanalytics*), refers to the application of algorithmic management, to monitor workers and their activities. More specifically, the survey asks whether the company uses data analytics to monitor employees' performance. The inclusion of this latter variable is quite original and offers a precise measure of the extent to which algorithmic management is used as a mechanism of control of the workforce. Hence, the difference between technical control and forms of control that employs data analytics is that technical control is not necessarily digitally enabled and does not necessarily involve data collection and processing to monitor employees.

It is worth stressing that the different forms of control are not mutually exclusive and may operate simultaneously. On the other hand, the adoption of one form of innovation may influence a given type of control but not others. For example, there is evidence that digitalisation of workplaces is often associated with an increase in technical control and algorithmic management and at the same time a reduction in the level of direct control exercised by managers (Butollo et al., 2019).

All the variables of interest are binomial. Those variables that were originally multinominal (*dirctrl2* and *techctrl*) have been redefined. Specifically, we recoded the variable *dirctrl2* to have a value of 1 if less than 40% of the employees organise autonomously their work, and of 0 otherwise. Similarly, *techctrl* takes a value of 1 in the case at least 40% of the workforce the pace of work is determined

[2] This point is also stressed by the authors of the ECS, according to which "the way innovation is captured in the ECS 2019 is inspired by the conceptualisation of technological innovation as outlined in the 2005 and 2009 versions of the Oslo Manual" (Eurofound & Cedefop, 2020, p. 29).

by machines or computers, and a value of 0 otherwise. For more details about the construction of the indicators see Table A1 in the appendix.

It follows that, as to direct control, values of 0 indicate that workers take decisions autonomously while values of 1 that managers decide the tasks performed by employees. In the case of indirect control indicators, values of 0 indicates that workers do not have their pace determined or monitored by machines while 1 means the opposite.

4 Descriptive statistics

In this section, we present a set of descriptive statistics to show the behaviour of the main variable of interest. To begin with, Table 1 tabulates the distribution of *innoproc* and *diginn,* the main independent variables of our empirical analysis, that is the four indicators of control. Digital innovation is more common than process innovation which may reflect the growing adoption of ICT solutions. One-third of the firms have introduced process innovations in the three years before the interview, while more than half of the firms in the sample have introduced digital innovations. One possible objection to the use of two alternative measures of innovation is that they are highly correlated. Firms that experience process innovation may also have a higher probability of experiencing digital innovation. As Table 1 shows, this is often the case. More than one-third of those firms that introduce digital innovations are also implementing process innovation strategies. However, it should be appreciated that in most cases firms record only one type of innovation. Moreover, the majority of the firms that introduced digital innovation did not experience process innovation. Hence, it seems appropriate to distinguish between the two types of innovations.

Table 1: Number of firms that experience process and digital innovation. Source: ECS 2019.

		Digital innovation		
		No	Yes	Total
Process innovation	No	7,496	6,545	14,041
	Yes	2,017	3,956	5,974
	Total	9,513	10,502	20,015

We then consider the relevance of process and digital innovation among European firms (Figure 1). Since one of the objectives of the paper is to explore possible regional differences across European countries, we split the 28 European countries into four groups: Core European (CE) countries, Southern European (SE) countries, Eastern European (EE) countries, and Nordic Countries (NC).[3] This grouping reflects a common procedure in the literature (for similar classifications see Riso 2020; Fana & Villani 2022). The figure shows the already mentioned fact that digital innovation is more common than process innovation across all the regions. As to regional specificities, the most salient difference is the highest presence of innovative firms among Southern European countries and the lower propensity of Eastern European countries to engage in digital innovation compared to the other group of countries.

[3] CE countries: Austria, Belgium, France, Germany, Ireland, Luxembourg, Netherlands and the UK; SE countries: Cyprus, Greece, Italy, Malta, Portugal and Spain; EE countries: Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia; NC: Denmark, Finland and Sweden.

A peculiarity emerging from the figure is that firms in SE countries appear to be the most innovative ones, while those in Core European countries (e.g. Germany) result to be the least innovative ones. This image stands against common sense, which usually depicts the opposite picture, with Core countries more innovative compared to Southern countries. This outcome is not a novelty when employing ECS data and it has been discussed also by other authors. Grande et al. (Grande et al., 2020) consider that this outcome can be partially explained by managers' bias in reporting since the response is subjective. Moreover, this result may be influenced by firm sampling. The ECS covers exclusively firms with at least 10 employees, so that "if countries vary [...] in the size composition on firms, then the comparison would be affected" (Grande et al., 2020). Importantly, it should also be considered that these figures are substantially in line with other similar surveys realised in recent years. For example, the latest edition of the European Innovation Scoreboard (Hollanders & Es-Sadki, 2021, fig. 6) reports that Southern European countries report the fastest change in the innovation index, followed by NC, which is coherent with the values of Figure 1. Therefore, these figures should not be interpreted as an indicator of the *absolute level* of innovation. Rather, they should be regarded as a proxy of the *change* in innovation in the latest years. This view is shared by the authors of the European Innovation Scoreboard, who argue that "between 2014 and 2021, there has been a moderate rate of convergence in innovation performance between Member States, with lower performing countries, on average, improving their level of innovation performance at a higher rate than higher performing countries." (Hollanders & Es-Sadki, 2021, p. 20). In light of these considerations, it is plausible to find SE countries among those with the highest innovative scores.

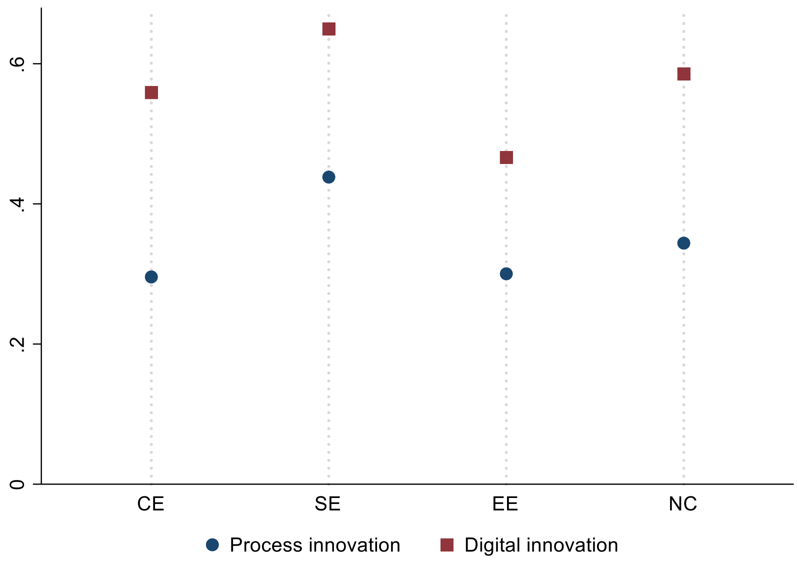

Figure 1: Process innovation and digital innovation. Average values by region. Source: Authors' elaboration using ECS 2019.

As to the size of the establishments, Table 2 shows that most of the sample (82.8% on average) is represented by firms with 10 to 49 employees, approximately 15% by medium-sized firms (50 to 249 employees), and a small fraction of the total is composed of big firms (250 or more employees). The presence of these three groups of firms is quite evenly distributed across regions. Perhaps, the most notable difference is the higher presence of firms with 10 to 29 employees in SE compared to the other regions. It is important to consider the size of the firms participating in the ECS because both processes of innovations tend to become more relevant with the size of the firm (Figure 2). The share of firms that record process innovation grows from approximately 30% in the case of smaller firms to 47% in the case of bigger firms. These figures are higher in the case of digital innovation, where this indicator takes a value of one in half of the smaller firms and increases to 80% in bigger firms.

Table 2: Distribution of firms by region and size. Share (%) of the total by region. Source: Authors' elaboration using ECS 2019.

	Number of employees		
	10 to 49	50 to 240	250 or more
CE	81.5	15.9	2.6
SE	86.3	11.6	2.1
EE	81.9	15.1	3.0
NC	83.7	14.2	2.1
Total	82.8	14.7	2.5

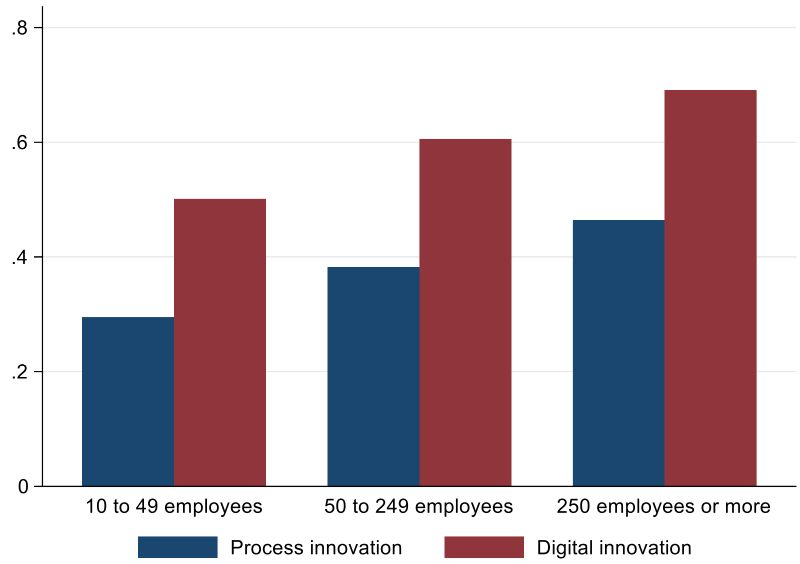

Figure 2: Process and digital innovation by firm size. Average values. Source: Authors' elaboration using ECS 2019.

Figure 3 reports the average values for all the four control indicators presented in the previous section in the four European regions. It can be appreciated that there are some relevant differences in the average values across different groups of countries. On the one hand, workers in EE countries (followed closely by SE countries) experience higher levels of control (both direct and indirect). This is coherent with other findings and with the reduced attention that the topic of employee monitoring does not find considerable space in the policy agenda and industrial relations (Riso, 2020). On the other hand, NC stands out from the other groups of countries as the region where workers are subject to the lowest degree of control and enjoy relatively higher autonomy in the organisation of their tasks. This aspect seems in line with the so-called Nordic Model of management (Rolfsen, 2013) which embeds a high degree of autonomy and participation of the workforce in the decisions involving the production process. At the same time, it can be observed that the heterogeneity across regions varies across indicators. Regional heterogeneity is more evident concerning direct control indicators, while it is more nuanced in the case of indirect control indicators. This aspect suggests that while firms can have quite different degrees of formal control, indirect control exercised via monitoring tools and equipment is more equally distributed across European countries.

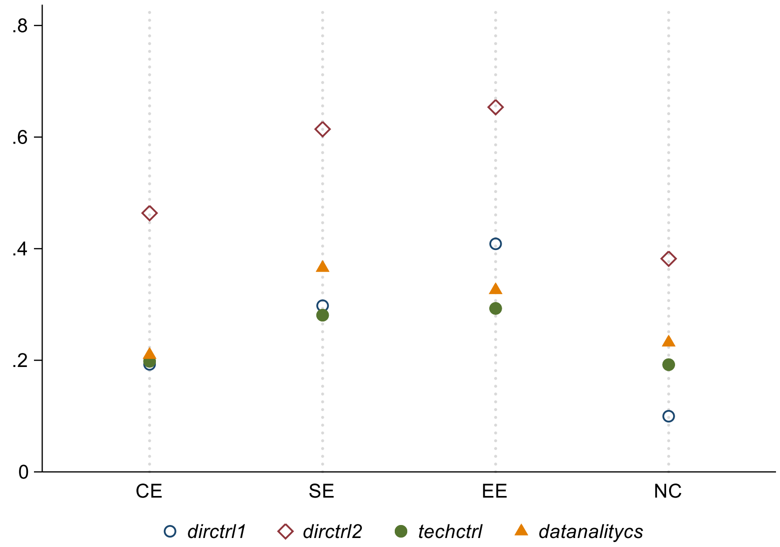

Figure 3: Direct and technical control indicators. Average values by region. Source: Authors' elaboration using ECS 2019.

Narrowing the focus on the control exercised via data analytics (Figure 4), we observe that the use of this form of monitoring is more frequent in the logistics (35%), followed by ICT services (32%) and wholesale-retail activities (30%), while it is less used in Real Estate activities (12%) and constructions (18%). This distribution in algorithmic management is coherent with the finding of other authors who show that this technologies are more common in logistic services (Mateescu & Nguyen, 2019; Wood, 2021).

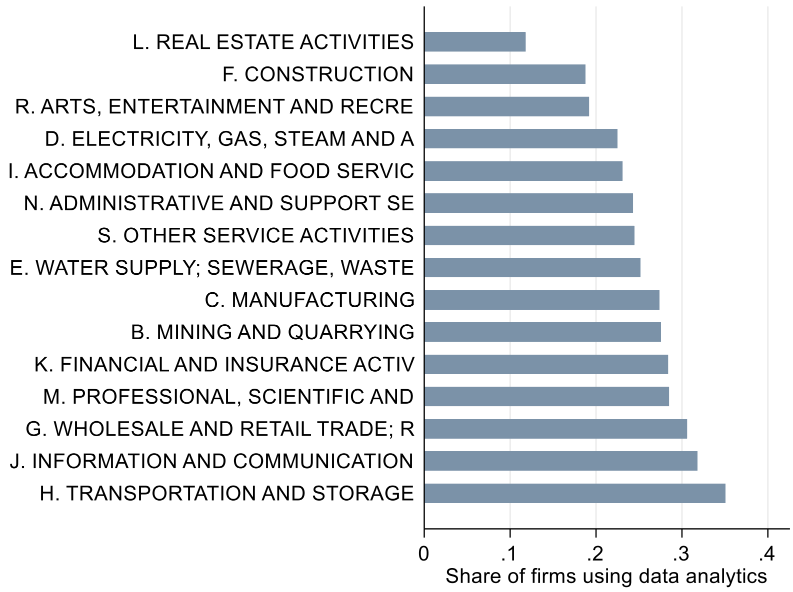

Figure 4: Algorithmic management by industry. Source: Authors' elaboration using ECS 201

Figure 5 provides a preliminary exploration at the country level of the relationship between innovation (process and digital) and the indicators of direct and indirect control. Results show that there is a mild positive relationship between process innovation and the level of direct and indirect control. Countries with a higher level of innovation are also those where firms control more (directly and indirectly) their employees. The opposite relationship holds between digital innovation. Although the correlation is not particularly strong, more innovative countries are also those where the level of technical control is below the average level.

Another interesting feature to highlight is that the groups of countries are quite clustered. Broadly speaking, CE countries tend to concentrate in the bottom-left quadrants, indicating a below-average level of innovation and a below-level of control. EE countries mostly gather in the upper-west quadrant, with relatively high levels of control and a lower degree of innovation. SE countries (upper-east quadrants) are on average more innovative and with a higher degree of control, while NC record the lowest degree of control while being relatively more innovative.

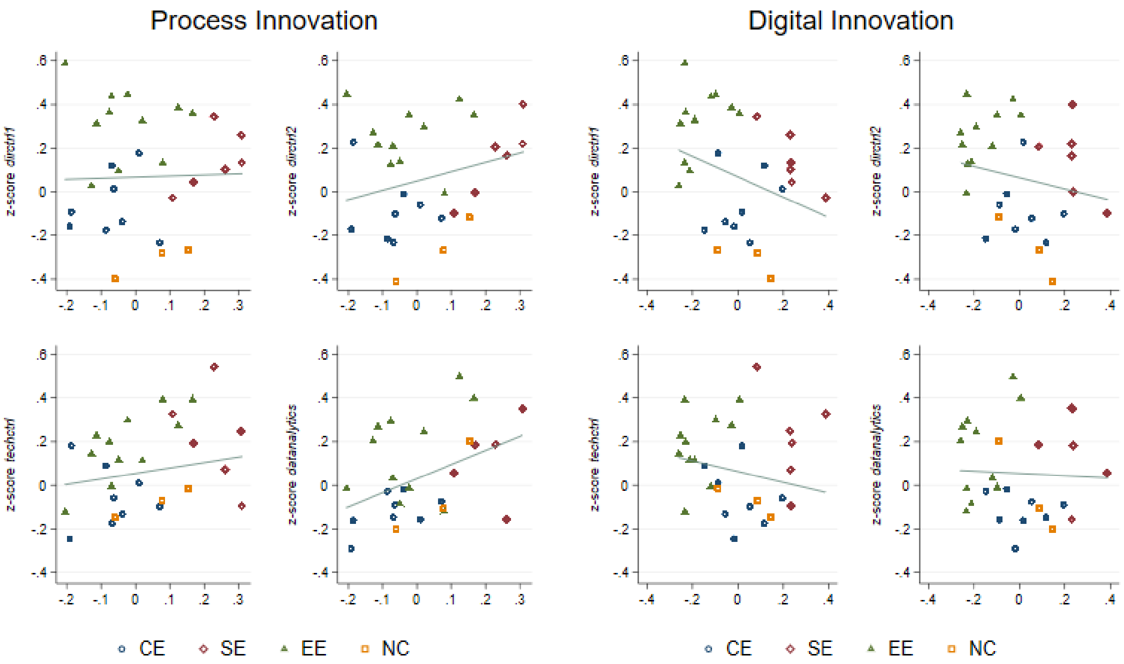

Figure 5: Z-scores of process and digital innovation vs z-scores direct and indirect control indicators. Note: The x axis shows the z-scores of process innovation (left panel) and digital innovation (right panel). Source: Authors' elaboration using ECS 2019 data.

At the same time, we should note that Figure 4 is not informative of the relationship between the level of innovation and control (direct and indirect) at the firm level. We start exploring this link in Table 3, which reports the t-tests of each pair of dependent and independent variables. This table suggests that firms investing in process or digital innovation are characterised by a higher level of technical control (techctrl) and algorithmic management (datanalytics). The positive link between digital innovation and algorithmic management can be seen as a "natural" outcome: in order to have algorithmic management firms necessarily need to introduce some sort of digital innovation. However, as it will be clearer by the end of the paper, while digital innovation is a requirement for algorithmic management, the opposite is not true. Conversely, a negative and significant association is found between direct control and both forms of innovation, but for the relationship between digital innovation (dirctrl2) and the general form of supervisory at the firm level (dirctrl1).

Table 3: Mean characteristics between innovative and non-innovative establishments.

	Process Innovation	No Process Innovation	Diff.	Digital Innovation	No Digital Innovation	Diff.
dirctrl1	0.2302	0.2588	-0.0285**	0.2380	0.2470	-0.0097
dirctrl2	0.4948	0.5431	-0.0483***	0.5066	0.5374	-0.0308**
techctrl	0.2850	0.2110	0.0739****	0.2541	0.2133	0.0408***
datanalytics	0.3970	0.2140	0.1829***	0.3247	0.2088	0.1158***

Source: Authors' elaboration using ECS 2019. Note: two-tailed test performed on the difference; *** p<0.001; ** p<0,01; * p<0.05

Overall, what emerges from this preliminary analysis is that there is a link between innovation and technology. Importantly, this relationship is not unidirectional, and it seems that there are some differences across groups of countries. This evidence hints at the fact that the introduction of new technologies may have an uneven effect across countries. In the next section, we explore in more detail these links with the use of econometrics.

5 Results

To explore the relationship between innovation and organisational practices we estimate the following logistic regression. This technique of analysis is common in studies that employ ECS and similar data (e.g. Jansen, 2014; Addison and Teixeira, 2020; D'Andria and Uebelmesser, 2021). Formally, the model is:

$$Control_{ic} = \beta Inn_{ic} + \gamma C_{ic} + \delta P_c + \varepsilon_{ic} \qquad (1)$$

Where $Control_{ic}$ is one of the four types of control prevailing in establishment *i*, in region c. The term Inn_{ic} is the innovation variable (*innoproc* or *diginn*) for establishment *i* in country c. As mentioned, this indicator takes a value of 1 if the firm has introduced a form of innovation in the three years prior to the survey and a value of 0 otherwise. C_{ic} is a vector of establishment characteristics, which includes the size and the years of activity of the establishment, whether the establishment recorded profits in 2018, the recent evolution of the labour force (if it reduced, increased or stayed the same), the share of employees with open-end contract and the share of workers that receive variable pay following management appraisal. The term P represents a vector of control variables, which includes country and industry fixed effects. Finally, the term ε is the error term.

Table 4 reports the main summary statistics of all variables used in the econometric exercise. Beyond the main variables of interest, for which we presented descriptive statistics in the previous section, the table shows that around 40% of firms interviewed experienced a reduction of the workforce while 13% of the firms expanded it. More than 40% of the workforce is employed under permanent contracts and for about 30% of the workers part of the pay is variable following linked to individual performance following management appraisal. The variable related to profits which takes values from 0 in the case of loss and 1 for positive profits shows that 88% of the establishments record positive profit in the previous period. Finally, in around one-third of the establishments at least 40% of workers receive extra pay linked to individual performance following management appraisal.

Table 4: Summary statistics.

Variable	mean	sd	min	max	N
Process Innovation (*procinn*)	0.335	0.472	0	1	21646
Digital innovation (*diginn*)	0.550	0.498	0	1	20182
Managers supervise workers tasks (*dirctrl1*)	0.293	0.455	0	1	21678
<40% employees are autonomous (*dirctrl2*)	0.588	0.492	0	1	21869
Pace determined by machines or computers (*techctrl*)	0.281	0.450	0	1	21869
Use of data analytics to monitor empl. (*datanalytics*)	0.315	0.465	0	1	21772
Negative employment change	0.403	0.491	0	1	21869
Stable employment	0.465	0.499	0	1	21869
Positive employment change	0.132	0.338	0	1	21869
> 40% permanent empl.	0.905	0.293	0	1	21869
Small (10 to< 49 empl.)	0.624	0.484	0	1	21869
Medium 50 to 249 empl.)	0.286	0.452	0	1	21869
Large (>250 empl.)	0.090	0.286	0	1	21869
profit	0.882	0.323	0	1	20112
variable pay	0.294	0.456	0	1	21869

Source: authors' elaboration using ECS 2019 data

Table 5 reports the results of the estimations of model (1) for the pooled model. Process innovation is strongly and negatively associated with both coefficients of direct control. This negative relationship is only partly confirmed in the case of digital innovation where the coefficient is significant only for dirctrl2. This indicates that more innovative firms have lower levels of direct control compared to non-innovative and that this relationship is more solid for firms that undergo process innovation compared to firms that introduce a digital innovation. Interestingly, the relationship between innovation and control is the opposite in the case of indirect control (Columns 5-8 in Table 5). In this case, the coefficients are positive and statistically significant for both types of innovation (process and digital). The size and the statistical significance of the coefficients indicate that the link between innovation and control is stronger in the case of indirect forms of control than it is for direct control. Hence, while the first type of direct control is still more widespread (see Figure 1), the relationship between innovation and control is more robust in the case of technical control and data analytics. Part of this outcome may relate to the fact that a necessary condition for indirect control to exist is that firms need to have introduced digital tools and software. Nevertheless, as we shall see in a moment, this does not automatically imply that more digitally innovative firms lead to higher levels of indirect control.

These findings provide an interesting picture of the relationship between different types of innovation and control at the workplace which appoints to a diversified picture in the type and level of control at the workplace. In general, more innovative firms are associated with lower direct managerial control and higher levels of indirect control. These results may indicate a changing nature of control at the workplace. With the diffusion of technologies in the future, it may be foreseen a generalised reduction of direct control in favour of technical control that is mediated by digital devices and a more intensive use of algorithms to monitor workers' activities and determine their pace.

Another interesting aspect to observe is that both direct and indirect control tend to increase with the size of the firm. This is an expected outcome, since bigger firms may need to implement tighter procedures to efficiently coordinate the production process. At the same time, the higher the share of workers whose pay depends on managers' appraisal the lower the direct control they are subject to and the higher the indirect control they experience, especially in terms of data analytics. This finding suggests that the use of algorithmic management could be a tool in managers' hands to carry out their traditional tasks: evaluate, discipline and command other's work and working conditions (including earnings). The fact that the coefficient for direct control is negative may suggest that managers appraisal of workers is not exercised via human control, but it is mediated by tools and data analytics.

We also find some weak evidence that the type of employment relation is negatively related to direct control. Although we do not have clear evidence in this sense, we can propose some possible mechanisms that determine this result. A higher share of permanent employees increases the probability of a more autonomous work environment from direct control. This may be because of different reasons. Permanent employees may have a deeper knowledge of the production process within the firm and therefore need to be less monitored than temporary workers. At the same time, workers' opposition to managerial control may be stronger in establishments characterised by a higher share of permanent workers. Finally, an expansion of the workforce is associated with higher direct control compared to a situation of decreasing employment. This may be related to the fact that firms hiring new employees may need closer supervision of the workforce.

Table 5: Estimation results. Full sample, pooled regression with countries fixed effects.

	(1) *dirctrl1*	(2) *dirctrl1*	(3) *dirctrl2*	(4) *dirctrl2*	(5) *techctrl*	(6) *techctrl*	(7) *datanalytics*	(8) *datanalytics*
Process Innovation	-0.253***		-0.287***		0.221***		0.719***	
	(0.0628)		(0.0604)		(0.0678)		(0.0619)	
Digital Innovation		-0.0527		-0.136**		0.264***		0.512***
		(0.0651)		(0.0624)		(0.0680)		(0.0644)
Empl. change (baseline: negative change)								
Stable employment	0.0949	0.118*	0.189***	0.217***	0.0282	0.0150	-0.120*	-0.198***
	(0.0681)	(0.0704)	(0.0640)	(0.0663)	(0.0700)	(0.0709)	(0.0661)	(0.0678)
Positive change	0.259***	0.324***	0.264***	0.230**	-0.0814	-0.0595	0.152	0.0892
	(0.0989)	(0.102)	(0.0994)	(0.104)	(0.104)	(0.108)	(0.0993)	(0.102)
permanent empl.	-0.0320	-0.0256	-0.0963***	-0.0977***	0.0316	0.0424*	-0.000321	0.00270
	(0.0207)	(0.0221)	(0.0206)	(0.0217)	(0.0226)	(0.0235)	(0.0234)	(0.0242)
profit	0.0419	0.0382	0.0702	0.0709	0.0544	0.0620	-0.0913*	-0.0924*
	(0.0439)	(0.0460)	(0.0451)	(0.0470)	(0.0479)	(0.0500)	(0.0474)	(0.0487)
Size (baseline: 10-49 empl.)								
59-249 employees	0.141**	0.141**	0.451***	0.457***	0.201***	0.183**	0.543***	0.516***
	(0.0692)	(0.0717)	(0.0691)	(0.0716)	(0.0711)	(0.0739)	(0.0698)	(0.0718)
> 250 employees	0.438***	0.427***	0.480***	0.530***	0.263***	0.233**	0.728***	0.678***
	(0.0991)	(0.0999)	(0.0987)	(0.101)	(0.0900)	(0.0923)	(0.0914)	(0.0897)
establishment age	0.0273	0.0324	0.00562	-0.00241	0.0306	0.0351	-0.115***	-0.117***
	(0.0313)	(0.0331)	(0.0302)	(0.0317)	(0.0327)	(0.0338)	(0.0307)	(0.0317)
variable pay	-0.181***	-0.184**	-0.446***	-0.473***	0.204***	0.188**	0.330***	0.333***
	(0.0698)	(0.0731)	(0.0678)	(0.0702)	(0.0714)	(0.0740)	(0.0668)	(0.0694)
Constant	-1.968***	-2.159***	1.010**	1.148**	-1.284***	-1.551***	-1.015**	-1.020**
	(0.360)	(0.376)	(0.500)	(0.530)	(0.456)	(0.490)	(0.493)	(0.516)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19,457	18,143	19,603	18,268	19,603	18,268	19,559	18,237

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Similar results are found when process and digital innovation are employed in the same specification (see table A2 in the appendix). Process innovation shows significant negative coefficients with the indicators of direct control and positive and significant in the case of technical control and data analytics. On the other hand, there is no significant relationship between digital innovation and dirctrl1 and a weak negative relationship in the case of dirdrctrl2. Finally, digital innovation is positively and significantly correlated with the use of technical control and data analytics. Also in this case, it should be noted that, between the four dependent variables, the coefficients are larger in the case of data analytics, indicating the important relationship between forms of innovation and data analytics.

In a second specification, we interact the two types of innovation to investigate if incurring in both process and digital innovations may have a different link with the level of control compared to firms that only implement only one type of innovation. To this end, we estimate the following specification:

$$Control_{ic} = \beta Innoproc * DigInn_{ic} + \gamma C_{ic} + \delta P_c + \varepsilon_{ic} \quad (2)$$

The results of Table 5 are reinforced when considering the simultaneous presence of process and digital innovation. Table 6 shows that except in the case of dirctrl1, the relationship with control is stronger when firms record both process and digital innovation than when only one type of innovation is present. In particular, the coefficients associated with direct control tend to decrease when firms experience both process and digital innovation, while the opposite relationship holds for indirect control. Looking at the different effects on our dependent variables, it is worth highlighting that the strongest effect is associated with the probability of using data analytics to monitor workers' activities compared to the variables of direct control and technical control. This finding provides support to the idea that the relationship between innovation and control is stronger in the case of forms of control that use data analytics, rather than more traditional forms of direct and technical control.

Table 6: Pooled regressions with interaction between process and digital innovation.

	(1) *dirctrl1*	(2) *dirctrl2*	(3) *techctrl*	(4) *datanalytics*
No innoproc No diginn (baseline)*				
No innoproc diginn*	-0.0587	-0.115	0.295***	0.501***
	(0.0800)	(0.0776)	(0.0847)	(0.0824)
innoproc No diginn*	-0.314***	-0.325***	0.268**	0.757***
	(0.100)	(0.104)	(0.115)	(0.109)
innoproc diginn*	-0.245***	-0.379***	0.412***	1.059***
	(0.0861)	(0.0803)	(0.0901)	(0.0844)
Empl. change (baseline: negative change)				
Stable empl.	0.0770	0.172**	0.0379	-0.0964
	(0.0713)	(0.0671)	(0.0727)	(0.0691)
positive change	0.303***	0.212**	-0.0622	0.162
	(0.103)	(0.105)	(0.109)	(0.104)
permanent empl.	-0.0239	-0.0929***	0.0410*	-0.000526
	(0.0221)	(0.0216)	(0.0236)	(0.0245)
profit	0.0370	0.0675	0.0649	-0.0877*
	(0.0463)	(0.0472)	(0.0502)	(0.0495)
Size (baseline: 10-49 empl.)				
59-249 employees	0.147**	0.474***	0.174**	0.504***
	(0.0720)	(0.0718)	(0.0743)	(0.0726)
> 250 employees	0.459***	0.555***	0.213**	0.634***
	(0.100)	(0.101)	(0.0933)	(0.0918)
establishment age	0.0295	-0.00605	0.0371	-0.121***
	(0.0332)	(0.0318)	(0.0341)	(0.0321)
variable pay	-0.174**	-0.461***	0.190**	0.319***
	(0.0735)	(0.0709)	(0.0748)	(0.0694)
Constant	-2.072***	1.239**	-1.629***	-1.238**
	(0.377)	(0.542)	(0.493)	(0.526)
Country FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Observations	18,019	18,137	18,137	18,108
Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1				

Finally, we investigate the relationship between innovation and control across different regions adding regional fixed effects to model (1). This is necessary to establish to what extent the relationship between innovation and control varies across regions. As discussed in the previous sections, the type and degree of control that workers are subject to can be the result of social practices and institutional factors and are not uniquely determined by the technology in use. Overall, the main findings do not change under this specification. However, it is interesting to note that there are some differences between regions. More specifically, compared to CE countries (the baseline region), SE and EE show higher levels of control, indicating that in these regions the level of control is more pervasive. Conversely, NC show relatively lower and significant coefficients when it comes to direct forms of control.

Table 7 Pooled regressions with regional fixed effects.

	(1) *dirctrl1*	(2) *dirctrl1*	(3) *dirctrl2*	(4) *dirctrl2*	(5) *techctrl*	(6) *techctrl*	(7) *datanalytics*	(8) *datanalytics*
innoproc	-0.237***		-0.254***		0.218***		0.727***	
	(0.0624)		(0.0597)		(0.0671)		(0.0607)	
diginn		-0.0562		-0.130**		0.228***		0.487***
		(0.0642)		(0.0610)		(0.0671)		(0.0635)
Group of countries (baseline: Core Europe)								
Southern Europe	0.572***	0.548***	0.559***	0.555***	0.404***	0.391***	0.686***	0.765***
	(0.0714)	(0.0755)	(0.0644)	(0.0671)	(0.0733)	(0.0750)	(0.0692)	(0.0708)
Eastern Europe	1.078***	1.092***	0.842***	0.841***	0.472***	0.480***	0.445***	0.503***
	(0.0748)	(0.0776)	(0.0717)	(0.0741)	(0.0762)	(0.0787)	(0.0728)	(0.0752)
Northern Countries	-0.703***	-0.755***	-0.326***	-0.350***	0.0156	0.0242	0.124	0.155**
	(0.0916)	(0.0976)	(0.0670)	(0.0704)	(0.0822)	(0.0843)	(0.0764)	(0.0787)
Empl. change (baseline: negative change)								
Stable empl.	0.0652	0.0868	0.164***	0.188***	0.00554	-0.00947	-0.144**	-0.226***
	(0.0669)	(0.0694)	(0.0628)	(0.0651)	(0.0692)	(0.0705)	(0.0650)	(0.0671)
positive change	0.240**	0.306***	0.251**	0.221**	-0.0661	-0.0382	0.192*	0.130
	(0.0980)	(0.101)	(0.0980)	(0.102)	(0.103)	(0.108)	(0.0999)	(0.103)
Permanent empl	-0.0388*	-0.0341	-0.0855***	-0.0871***	0.0207	0.0275	0.00592	0.00699
	(0.0199)	(0.0213)	(0.0200)	(0.0211)	(0.0227)	(0.0237)	(0.0228)	(0.0237)
profit	0.0376	0.0292	0.0941**	0.0910**	0.0411	0.0479	-0.0709	-0.0711
	(0.0433)	(0.0454)	(0.0441)	(0.0458)	(0.0467)	(0.0490)	(0.0465)	(0.0481)
Size (baseline: 10-49 empl.)								
59-249 employees	0.154**	0.157**	0.452***	0.457***	0.178**	0.162**	0.511***	0.483***
	(0.0683)	(0.0710)	(0.0673)	(0.0700)	(0.0696)	(0.0723)	(0.0683)	(0.0701)
> 250 employees	0.448***	0.441***	0.499***	0.552***	0.241***	0.221**	0.707***	0.671***
	(0.0977)	(0.0990)	(0.0975)	(0.0995)	(0.0884)	(0.0907)	(0.0900)	(0.0885)
establishment age	0.0143	0.0217	-0.0195	-0.0266	-0.00361	-0.000538	-0.143***	-0.152***
	(0.0307)	(0.0324)	(0.0293)	(0.0307)	(0.0319)	(0.0332)	(0.0303)	(0.0313)
variable pay	-0.211***	-0.216***	-0.415***	-0.439***	0.153**	0.133*	0.303***	0.309***
	(0.0687)	(0.0719)	(0.0659)	(0.0683)	(0.0695)	(0.0724)	(0.0655)	(0.0686)
Constant	-1.483***	-1.715***	1.117**	1.257**	-1.351***	-1.584***	-1.188***	-1.163**
	(0.338)	(0.354)	(0.471)	(0.502)	(0.428)	(0.460)	(0.460)	(0.469)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19,457	18,143	19,603	18,268	19,603	18,268	19,559	18,237

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

In light of the findings of Table 7, we move one step further to establish to what extent the relationship between innovation and forms of control changes across regions. We thus run region-specific regressions of model (1). From this analysis (see Figure 6), it emerges that there are interesting differences across regions. The negative relationship between process innovation and both indicators of direct control holds for CE and EE countries (as in Table 5) but they are not statistically significant in SE countries and NC. On the other hand, process innovation has a positive and significant relationship with the use of data analytics to monitor employees (datanalytics) in all regions, while it is significant only in SE and EE countries when it comes to the determination of the pace of work by machines or computers (techctrl). Similar results are found for the association between digital innovation and indirect control, although in this case the magnitude for data analytics is slightly lower.

Finally, the link between digitalisation and direct control is confirmed to be rarely significant. The only case in which we find statistical significance is for SE countries for dirctrl2.

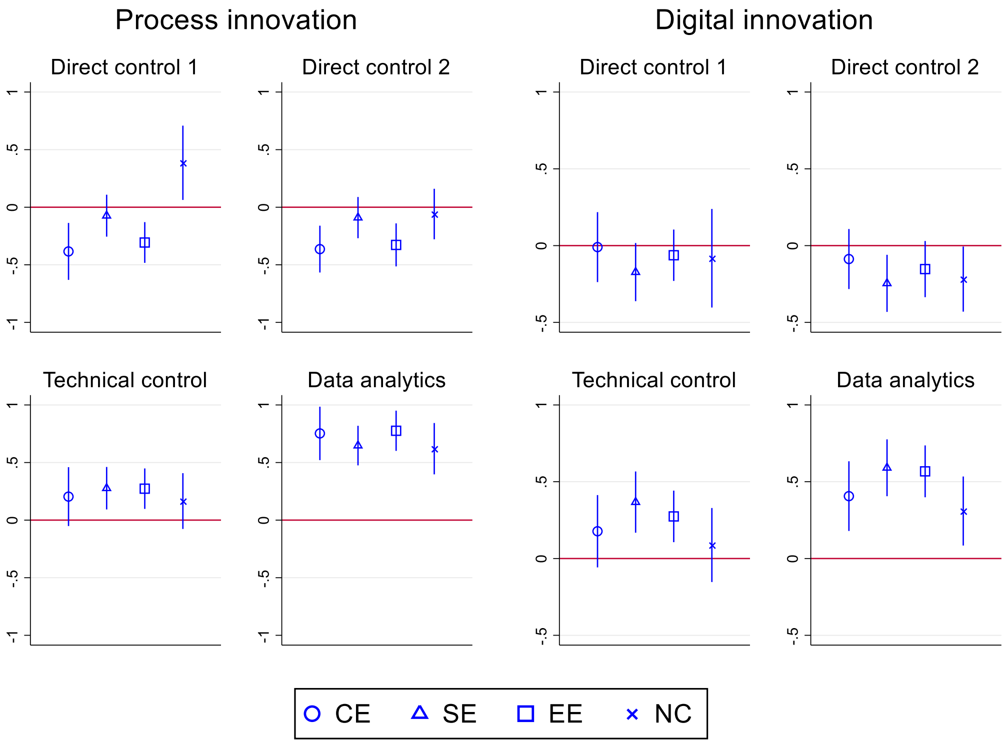

Figure 6: Estimation coefficients by region. Note: the distance from 0 indicates the higher/lower level of direct and indirect control. Statistical significance at 95%.

Overall, these findings show that there are relevant differences across regions regarding the relationship between innovations and the degree of control. The link between digital innovation and data analytics is particularly pronounced in SE and EE countries which suggests that in these groups of countries the adoption of new digital innovation plays a relatively more important role in reshaping work organisation at the establishment level. In general, the relationship between innovation and control is stronger in the case of indirect forms of control than it is for direct control. This is a noticeable result that indicates that in more innovative firms the functions of control exerted by tools and algorithmic management, rather than direct control exercised by managers, is higher than in less innovative firms. This evidence, however, could make us overlook the role played by more traditional ways of monitoring. Even though innovation shows a weaker relationship with direct control than with indirect control, direct control (especially dirctrl1) is still very pervasive among European firms (see Figure 3). Even though in the future indirect forms of monitoring workers' performances will become relatively more present, direct control is still an important feature of work organisation.

6 Conclusions

This paper has explored the relationship between innovation and of control at the workplace. To do so, we have employed information from the latest edition of the ECS, which is one of the few datasets that map both innovation indicators and organisational methods at the firm level. A major novelty of this paper is that we are able to distinguish between two types of innovation, process and digital, and two types of control, a more traditional type of control exerted by the management of the establishment (direct control) and a more indirect form of control. Notably, we could also differentiate between a more traditional modality of indirect control, which employs machines and digital tools, and data analytics. The latter is emerging as a tool for employee's monitoring, indicating the deployment of algorithmic management practices in the enterprise.

The empirical findings provide a multifaceted picture. First, innovation has opposite relationships with direct and indirect control. More innovative firms tend to record lower levels of direct control. Within these firms, workers tend to be supervised less closely by the management. This finding does not imply that more innovative establishments record a *generally* lower level of control. In fact, more innovative firms are also those in which indirect forms of control (i.e. the pace of work is determined/monitored by a machine/data analytics) are more developed. The link between innovation and indirect control is strongly positive.

These results are even more important considering the progress of digitalisation in European companies. The evidence from the ECS shows that digital innovation is more widespread than process innovation. Thus, the positive link between digital innovation and control is likely to be more pervasive than the link between process innovation and control. The process of digitalisation of the firms will likely continue to expand in the near future and so could intensify the role of indirect forms of control. In this respect, it is interesting to observe that the link between innovation and indirect control is stronger in the case of data analytics than it is for technical control. This finding appoints to the rising importance that data management have in monitoring workers. Despite our study does not allow to provide a causal link between innovation and increased monitoring at the workplace, it is possible to assert that the degree of indirect control (especially algorithmic management) may increase over time both in absolute levels and in relative terms compared to the level of direct control and technical control.

These aspects pose numerous novelties and challenges to the way work is organised. Higher indirect control may change the way social relations are shaped with firms. One possibility is that the disintermediation of the relations of productions derived from higher indirect control will increase employees' alienation from the process of production, as it has been argued by other authors (Glavin et al., 2021). The rise of indirect control may also entail an increase in the fragmentation of the relations of production, impacting the workers' representation institutions and affecting the bargaining process (Wood, 2021).

Of course, the pace of production, the algorithms, the monitoring devices are ultimately determined by humans and there is no *a priori* outcome that derives from their deployment. We believe that our findings should not be interpreted as a deterministic and unavoidable result of the introduction of new technologies where human agency has no role to play. In this respect, it is relevant to observe that there are significant differences in the way process and digital innovation relate to direct and indirect control. The link between innovation and control is much stronger in SE and EE countries than it is in CE countries and NC. These findings suggest that there is some variability in the way innovations relate to forms of control. Institutions and organisational practices may differ considerably across countries and can evolve in time, resulting in some heterogeneity in the impact that a new technology has on the work organisation. Digital innovations offer new tools for monitoring and coordinating the production process but the impact that this innovation will have on the workers will depend on the use that is made of it.

More generally, these findings posit some important questions regarding the future of work. Should it be confirmed that the process(es) of innovation(s) entails a reduction in the degree of control directly exerted by the management, then it is possible that a good portion of the duties carried out by managers will tend to become obsolete which leads to asking what will happen to managerial occupations. This process may lead to a change in the absolute requirements of managerial positions (with a reduction of the presence of managerial positions) and/or a change in their functions, with a lower content of direct monitoring which will then be taken over by machines. This mechanism may have important implications for the literature on automation and job polarisation/displacement (e.g. Goos et al. 2009; Acemoglu & Restrepo 2018), as would entail that jobs at the top of the occupational distribution may be replaced following the introduction of new technologies.

Hence, this paper contributes to shedding light on the link between different forms of innovation and direct and indirect control, but also provides hints for future research. One possibility to expand the topic would be to assess the changes in the work organisation associated with the introduction of technology over a longer period. A key aspect that needs to be explored in more detail is to what extent the introduction of new technologies replaces traditional forms of control. More research is also needed on the institutional factors and social forces that may play a role in mediating the impact that innovation has on the tasks performed by workers. This is a crucial duty in an era in which the rise of new technologies poses several challenges regarding the future of work. Acknowledging the fact that there is no *a priori* outcome that derives from the introduction of new technologies and that different factors can influence the impact they have on the work organisation may help to smooth those positions that envisage a deterministic outcome that follows the introduction of new technologies. Last but not the least, it is paramount that the normative discussion on the introduction of new technology attempts at reconciling the introduction of new technologies with the improvement of the working conditions.

7 References

Acemoglu, D., & Restrepo, P. (2018). Automation and New Tasks: The Implications of the Task Content of Technology for Labor Demand. *Journal of Economic Perspectives*, *33*(2), 3–30.

Addison, J. T., & Teixeira, P. (2020). Trust and Workplace Performance. *British Journal of Industrial Relations*, *58*(4), 874–903. https://doi.org/10.1111/bjir.12517

Baiocco, S., Fernández-Macías, E., Rani, U., & Pesole, A. (2022). The Algorithmic Management of work and its implications in different contexts. *Forthcoming*, 1–44.

Becker, M. C. (2004). Organizational routines: A review of the literature. *Industrial and Corporate Change*, *13*(4), 643–677. https://doi.org/10.1093/icc/dth026

Berger, T., & Frey, C. B. (2016). Structural Transformation in the OECD: Digitalisation, Deindustrialisation and the Future of Work. *OECD Social, Employment and Migration Working Papers*, *193*, 1–52.

Braverman, H. (1974). *Labor and monopoly capital*. Monthly Review.

Brynjolfsson, E., & McAfee, A. (2014). *The second machine age*. WW Norton & Company.

Buer, S. V., Fragapane, G. I., & Strandhagen, J. O. (2018). The Data-Driven Process Improvement Cycle: Using Digitalization for Continuous Improvement. *IFAC-PapersOnLine*, *51*(11), 1035–1040. https://doi.org/10.1016/j.ifacol.2018.08.471

Butollo, F., Jürgens, U., & Krzywdzinski, M. (2019). From Lean Production to Industrie 4.0: More Autonomy for Employees? In U. Meyer, S. Schaupp, & D. Seibt (Eds.), *Digitalization in Industry*. Palgrave Macmillan.

Carpanzano, E., Bettoni, A., Julier, S., Costa, J. C., & Oliveira, M. (2018). Connecting humans to the loop of digitized factories' automation systems. *Lecture Notes in Mechanical Engineering*, *0*(9783319895628), 180–193. https://doi.org/10.1007/978-3-319-89563-5_14

Cassetta, E., Monarca, U., Dileo, I., Di Berardino, C., & Pini, M. (2020). The relationship between digital technologies and internationalisation. Evidence from Italian SMEs. *Industry and Innovation*, *27*(4), 311–339. https://doi.org/10.1080/13662716.2019.1696182

D'Andria, D., & Uebelmesser, S. (2021). The relationship between profit-sharing schemes and R&D activities: evidence from German firm-level data. *Industry and Innovation*, *28*(8), 990–1016. https://doi.org/10.1080/13662716.2021.1929866

Dachs, B., Hud, M., Koehler, C., & Peters, B. (2017). Innovation, creative destruction and structural change: firm-level evidence from European countries. *Industry and Innovation*, *24*(4), 346–381. https://doi.org/10.1080/13662716.2016.1261695

Delfanti, A. (2021). *Machinic dispossession and augmented despotism: Digital work in an Amazon warehouse*. *23*(1), 39–55. https://doi.org/10.1177/1461444819891613

Demirel, P., & Mazzucato, M. (2012). Innovation and Firm Growth: Is R&D Worth It? *Industry and Innovation*, *19*(1), 45–62. https://doi.org/10.1080/13662716.2012.649057

Edwards, R. (1982). Contested terrain: The transformation of the workplace in the twentieth century. *Science and Society*, *46*(2).

Eurofound. (2018). *Automation, digitalisation and platforms: Implications for work and employment*. Publications Office of the European Union.

Eurofound, & Cedefop. (2020). European Company Survey 2019: Workplace practices unlocking employee potential. In *European Company Survey 2019 series*. Publications Office of the European Union. http://eurofound.link/ef20001

Fana, M., Massimo, F. S., & Moro, A. (2021). Autonomy and control in mass remote working during the

Covid-19 pandemic. Evidence from a cross-professional and cross-national analysis. *LEM Working Paper Series, Scuola Superiore Sant'Anna, Laboratory of Economics and Management (LEM), Pisa*, *28*.

Fana, M., & Villani, D. (2022). Decomposing the Automotive Supply Chain: Employment, Value Added and Occupational Structure. *Structural Change and Economic Dynamics*, *xxxx*. https://doi.org/10.1016/j.strueco.2022.04.004

Felstead, A., Jewson, N., & Walters, S. (2003). Managerial control of employees working at home. *British Journal of Industrial Relations*, *41*(2), 241–264. https://doi.org/10.1111/1467-8543.00271

Friedman, A. (1990). Managerial Strategies, Activities, Techniques and Technology: Towards a Complex Theory of the Labour Process. In D. Knights & H. Willmott (Eds.), *Labour Process Theory* (pp. 177–208). Palgrave Macmillan, London. https://doi.org/https://doi.org/10.1007/978-1-349-20466-3_6

Glavin, P., Bierman, A., & Schieman, S. (2021). Powerless and Alone in the Gig Economy. *Work and Occupations*, *48*(4), 399–431. https://doi.org/10.1177/07308884211024711

Goos, M., Manning, A., & Salomons, A. (2009). Job polarization in Europe. *American Economic Review*, *99*(2), 58–63. https://doi.org/10.1257/aer.99.2.58

Grande, R., Muñoz, R., Bustillo, D., Fernández, E., & Ignacio, J. (2020). Innovation and job quality . A firm-level exploration. *Structural Change and Economic Dynamics*, *54*, 130–142. https://doi.org/10.1016/j.strueco.2020.04.002

Green, F., Felstead, A., Gallie, D., & Henseke, G. (2021). Working Still Harder. *ILR Review*, *X*, 1–30. https://doi.org/10.1177/0019793920977850

Hall, B. H. (2011). Innovation and Productivity. *NBER Working Paper N. 17178*.

Hollanders, H., & Es-Sadki, N. (2021). *European Innovation Scoreboard 2021*. Publications Office of the European Union.

Ingvaldsen, J. A., Holtskog, H., & Ringen, G. (2013). Unlocking work standards through systematic work observation: Implications for team supervision. *Team Performance Management*, *19*(5–6), 279–291. https://doi.org/10.1108/TPM-11-2012-0039

Jansen, G. (2014). Effects of union organization on strike incidence in EU companies. *ILR Review*, *67*(1), 60–85. https://doi.org/10.1177/001979391406700103

Jarrahi, M. H., Newlands, G., Lee, M. K., Wolf, C. T., Kinder, E., & Sutherland, W. (2021). Algorithmic management in a work context. *Big Data and Society*, *8*(2). https://doi.org/10.1177/20539517211020332

Kaasinen, E., Schmalfuß, F., Özturk, C., Aromaa, S., Boubekeur, M., Heilala, J., Heikkilä, P., Kuula, T., Liinasuo, M., Mach, S., Mehta, R., Petäjä, E., & Walter, T. (2020). Empowering and engaging industrial workers with Operator 4.0 solutions. *Computers and Industrial Engineering*, *139*. https://doi.org/10.1016/j.cie.2019.01.052

Kellogg, K. C., Valentine, M. A., & Christin, A. (2020). Algorithms at work: The new contested terrain of control. *Academy of Management Annals*, *14*(1), 366–410. https://doi.org/10.5465/annals.2018.0174

Leonardi, P. M., & Jackson, M. H. (2004). Technological determinism and discursive closure in organizational mergers. *Journal of Organizational Change Management*, *17*(6), 615–631. https://doi.org/10.1108/09534810410564587

Leso, V., Fontana, L., & Iavicoli, I. (2018). The occupational health and safety dimension of Industry 4.0. *La Medicina Del Lavoro*, *110*(5), 327–338. https://doi.org/10.23749/mdl.v110i5.7282

Marler, J. H., & Liang, X. (2012). Information technology change, work complexity and service jobs: A contingent perspective. *New Technology, Work and Employment*, *27*(2), 133–146. https://doi.org/10.1111/j.1468-005X.2012.00280.x

Mateescu, A., & Nguyen, A. (2019). Explainer: Algorithmic Management in the Workplace. *Data&Society Research Insitute*, *February*, 1603–1612.

Mohnen, P., & Hall, B. H. (2013). Innovation and Productivity: an Update. *Eurasian Business Review*, *3*(1), 47–65.

Noble, D. (1979). Social Chioce in Machine Design. In A. Zimbalist (Ed.), *Case Studies on the Labour Process* (Monthly Re, pp. 18–50).

OECD/Eurostat. (2018). Oslo Manual 2018. In *Handbook of Innovation Indicators and Measurement*. https://doi.org/10.1787/9789264304604-en%0Ahttps://www.oecd-ilibrary.org/science-and-technology/oslo-manual-2018_9789264304604-en%0Ahttps://www.oecd-ilibrary.org/science-and-technology/oslo-manual-2018_9789264304604-en

Piva, M., & Vivarelli, M. (2005). Innovation and Employment: Evidence from Italian Microdata. *Journal of Economics*, *86*(1), 65–83. https://doi.org/10.1007/s00712-005-0140-z

Riso, S. (2020). Employee monitoring and surveillance: the challenges of digitalisation. In *European Foundation for the Improvement of Living and Working Conditions.* Publications Offi ce of the European Union.

Riva, E., Lucchini, M., den Dulk, L., & Ollier-Malaterre, A. (2018). The skill profile of the employees and the provision of flexible working hours in the workplace: a multilevel analysis across European countries. *Industrial Relations Journal*, *49*(2), 128–152. https://doi.org/10.1111/irj.12207

Rolfsen, M. (2013). Teamwork within the Nordic model. *Team Performance Management: An International Journal*, *19*(5–6), 240–243. https://doi.org/10.1108/TPM-05-2013-0015

Taskin, L., & Edwards, P. (2007). The possibilities and limits of telework in a bureaucratic environment: Lessons from the public sector. *New Technology, Work and Employment*, *22*(3), 195–207. https://doi.org/10.1111/j.1468-005X.2007.00194.x

Thompson, P., & Laaser, K. (2021). Beyond technological determinism: revitalising labour process analyses of technology, capital and labour. *Work in the Global Economy*, *1*(1), 139–159. https://doi.org/10.1332/273241721x16276384832119

Wood, A. J. (2021). Algorithmic Management. Consequences for Work Organisation and Working Conditions. *Seville: European Commission*, *JRC124874*.

8 Annexes

Table A 1: Direct and indirect control variables. Source: Adapted from ECS 2019.

	variable	Original name ECS	Question
Direct control	*dirctrl1*	*supchek*	Different establishments use different approaches to manage the way employees carry out their tasks. Which of these two statements best describes the general approach to management at this establishment? 0: Managers control whether employees follow the tasks assigned to them 1: Managers create an environment in which employees can autonomously carry out their tasks
	dirctrl2	*comorg*	For how many employees in this establishment does their job include independently organising their own time and scheduling their own tasks? 0: At least 40% of employees 1: Less than 40% of employees
Indirect control	*techctrl*	*pcwkmach*	For how many employees at this establishment is the pace of work determined by machines or computers? 0: Less than 40% of employees 1: At least 40% of employees
	datanalytics	*itpermon*	Does this establishment use data analytics to monitor employee performance? 0: No 1: Yes

Table A2. Estimation results. Full sample, pooled regression with countries fixed effects.

	(1) *dirctrl1*	(2) *dirctrl2*	(3) *techctrl*	(4) *datanalytics*
Process innovation	-0.214***	-0.273***	0.164**	0.634***
	(0.0664)	(0.0642)	(0.0711)	(0.0653)
Digital innovation	-0.0363	-0.106*	0.240***	0.434***
	(0.0659)	(0.0634)	(0.0691)	(0.0659)
Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Observations	18,140	18,262	18,262	18,227

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

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