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How the three Ds affect firm pricing, markups and productivity

Digitalisation of firms and (type of) employment

by Sousso Bignandi, Cédric Duprez and Céline Piton

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Editorial

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Digitalisation of firms and (type of) employment*

S. Bignandi[a], C. Duprez[b], C. Piton[c]

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Abstract

This paper investigates the effects of digitalisation on firm-level employment and workforce composition in Belgium from 2003 to 2019, using a novel dataset that merges ICT expense data with administrative employment records. We find that digitalised firms experienced higher employment growth relative to non-digitalised firms, driven by both increased hiring and higher retention rates. The effect is particularly pronounced in large firms and reflects both faster employment growth in expanding firms and slower declines in shrinking firms. Digitalisation also significantly altered workforce composition, leading to a decrease in the share of low-educated workers and an increase in the share of highly educated workers, alongside shifts in the age distribution towards middle-aged workers. Our analysis employs a long-difference regression approach, well suited to capturing the gradual nature of ICT investments. While endogeneity concerns prevent causal interpretation, we show robust correlations between digitalisation and employment growth. The study contributes to the literature by providing a granular measure of digitalisation at firm level, offering new insights into the dynamics of worker turnover and sectoral differences, and by shedding light on the heterogeneous impact of digitalisation across worker education levels and age groups.

KEYWORDS: Digitalisation, employment, firms

JEL classification: D22, D25, J21, J24.

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[a] ULiège (HEC-Liege & CEDEM), 14 Rue Louvrex, 4000 Liège, Belgium. https://orcid.org/0000-0003-2693-4509

[b] Economics and Research Department, National Bank of Belgium, 14 Boulevard de Berlaimont, 1000 Brussels, Belgium.

[c] Economics and Research Department, National Bank of Belgium, 14 Boulevard de Berlaimont, 1000 Brussels, Belgium. https://orcid.org/0000-0001-6405-2959, corresponding author: Celine.Piton@nbb.be.

1 Introduction

The future of employment in the age of digitalisation is a central concern in academic, public and political discourse. Our paper contributes to this ongoing discussion by analysing how the adoption of digital technologies by firms in Belgium influenced their employment levels and workforce composition between 2003 and 2019. Our findings show that digitalised firms experienced greater employment growth compared to non-digitalised ones. This growth was driven by both higher rentention rates and increased hiring. The effect was particularly pronounced in large firms. It reflects not only faster growth by expanding firms but also a slower decline in employment among firms shrinking during this period. Furthermore, our results indicate a significant reduction in the share of low-educated workers, alongside a notable increase in highly educated ones. We also observed an increase in middle-aged workers and a decrease in older workers at digitalised firms.

Our analysis relies on a unique and comprehensive dataset that combines firm-level data with administrative employment records from 2003 to 2019. This rich dataset enables us to precisely track all digitalisation-related expenditure by firms, revealing an important stylised fact: ICT investment patterns tend to be continuous and gradual. This indicates that digitalisation entails an ongoing process of investment rather than one shot, large-scale investments.[1] This finding contrasts sharply with the adoption of automation and robots, which is typically characterised by spikes or lump-sum investment (Domini *et al.*, 2021; Bessen *et al.*, 2020, 2023; Antonioli *et al.*, 2024; Anghel *et al.*, 2024). Since we did not observe a clear before-and-after scenario, we could not use previous estimation strategies. Instead, we applied a long-difference regression approach (following Acemoglu and Restrepo, 2020), distinguishing between digitalised firms, i.e. those consistently above the median share of ICT expenditure, and non-digitalised firms, which do not follow this pattern. This approach is well suited to analysing phenomena that evolve slowly or manifest over time. Moreover, the long-difference method helps mitigate potential autocorrelation in the error term.

To ensure the robustness of our findings, we conducted several robustness tests. These included using alternative definitions for digitalisation and different control groups, as well as varying the analysis period. Our baseline effects remained consistent across these specifications.

While our findings indicate that digitalisation has a positive, significant and robust effect on employment, it is important to stress that these results should not be interpreted as causal due to the non-random nature of firm digitalisation. Firms that choose to digitalise tend to be larger, more productive and better resourced, thereby introducing potential endogeneity and limiting our ability to infer causality. Although our robustness tests control for these factors, thereby reinforcing the strength of our results, resolving the endogeneity issue would require the use of an instrumental variable. This approach is not currently feasible given our dataset and would require further research.

The impact of digitalisation on employment has been extensively studied in the academic literature, yet the findings remain inconclusive. Two primary views dominate. The first is the employment substitution effect, pursuant to which digital technologies replace workers,

[1] This is consistent with a finding by Bloom *et al.* (2012) in their study of the United States.

leading to job losses and higher unemployment (Keynes, 1930; Frey and Osborne, 2017; Brynjolfsson and McAfee, 2014; Acemoglu and Restrepo, 2018, 2020; Graetz and Michaels, 2018; Acemoglu *et al.*, 2022). These studies focus primarily on the industry-level implications of technological advancements. The second view, known as the employment creation effect, suggests that digitalisation drives an increase in total employment (Autor, 2015; Dutz *et al.*, 2018; OECD, 2019; Stehrer, 2019; Ghodsi *et al.*, 2020; Koch *et al.*, 2021; Dixon *et al.*, 2021; Aghion *et al.*, 2022; Miho *et al.*, 2023). Studies espousing this view often analyse the firm-level effects of technology adoption.

Our study contributes to the existing literature on workforce dynamics and technological change in several ways. First, while some previous research (e.g. Graetz and Michaels, 2018; Autor *et al.*, 2020) relied on firm-level data, few have combined detailed administrative employment data with firm-level digitalisation measures. Our paper leverages a unique dataset that merges firm-level ICT expenditure data with administrative employment records in Belgium, covering a substantial period from 2003 to 2019. This allows us to conduct a micro-level analysis that is rare in the current literature. In addition, many studies offer cross-sectional snapshots or short-term analyses (e.g., Criscuolo *et al.*, 2014). By analysing an extended period, our study provides a longitudinal perspective on digitalisation and employment. This long-term approach allows for the observation of trends and patterns that short-term studies might miss.

Another contribution of our research is the precision with which we measure digitalisation. Unlike many studies that rely on broad proxies for technological adoption, such as robot density (Graetz and Michaels, 2018) or Internet adoption (Akerman *et al.*, 2015), we use detailed firm-level ICT expenditure data. This allows us to accurately measure ICT adoption within firms and distinguish between different types of digital expenditure, such as on ICT goods and services.[2]

Moreover, we delve deeper into the mechanisms behind the net employment effect of digitalisation, focusing on firm size, growth rates and worker turnover (entries and exits). While prior studies have examined the net change in employment or task-based impacts (Bessen and Righi, 2019; Autor *et al.*, 2020), our analysis goes beyond these approaches by exploring workforce stability and turnover, providing new insight into how digitalisation affects employee dynamics within firms. The large sample size of our dataset also enables us to conduct sectoral analyses, distinguishing between manufacturing and non-manufacturing sectors, with a further distinction between construction, trade, transport and professional, technical and scientific services. This level of sectoral detail is rare in the literature, as most studies rely on survey data which lack the necessary granularity for such distinctions.

Finally, we contribute to the literature by analysing the composition of the workforce within firms. Unlike most labour market studies that focus on task-based methodologies (Autor and Dorn, 2013; Frey and Osborne, 2017), our dataset enables us to track changes in the educational composition (low-, medium-, and highly-educated workers) and age distribution

[2] Relying on survey data to study the link between ICT and exports and productivity within firms in Belgium, France and the Netherlands, Vancauteren *et al.* (2024) also provide some descriptive statistics on the type of ICT used by firms. They distinguish between broadband, website, computers, mobile internet, e-commerce, ICT specialists.

(young, middle-aged and older workers) within firms. This allows for a more granular analysis of how digitalisation reshapes workforce demographics.

Some studies look at the impact of technology on skill composition (Akerman *et al.*, 2015; Michaels *et al.*, 2014), often in a more aggregated manner. Autor *et al.* (2003) demonstrated how computerisation in the US shifted job skill demands by increasing demand for nonroutine cognitive tasks. Similarly, Brambilla and Tortarolo (2018) found that ICT adoption in Argentina's manufacturing sector increased the share of skilled workers. Our research extends these insights by investigating how digitalisation affects demand for workers with different education levels, thus contributing to the literature on skill-biased technological change (Katz and Murphy, 1992; Autor *et al.*, 2003; Michaels *et al.*, 2014).

The rest of the paper is structured as follows. Section 2 describes our dataset, while Section 3 sets out our definition and measurement of digitalisation alongside some descriptive statistics. Section 4 introduces our methodology, while Section 5 presents our results. The final section concludes the paper and discusses further research avenues.

2 Database

Our analyses rely on a detailed employer-employee database created by merging two datasets: one from the National Bank of Belgium (NBB) providing firm records and another from the Crossroads Bank for Social Security (CBSS) offering detailed information on workers.

The first dataset contains rich microlevel data on Belgian private-sector firms[3] over the period 2003 to 2019. It brings together information drawn from four comprehensive panel-level sources: (i) annual accounts filed with the Central Balance Sheet Office; (ii) business-to-business (B2B) transactions data;[4] (iii) international trade data; and (iv) National Social Security Office data. This allows us to extract firm-level information on value added, capital stock, sector of activity, domestic and foreign expenditures, as well as to construct our measure of firm digitalisation (see Section 3).

The second dataset, from the CBSS, includes data on all individuals registered as working in Belgium for at least one quarter over the period 2002 to 2019. It includes detailed information on personal characteristics, including the level of education and age. Education levels are categorised into three groups: the low-educated, those with at most a lower secondary degree; the middle-educated, who have an upper secondary diploma; and the highly-educated, who have a tertiary degree. They are derived from a combination of sources such as the Statbel 2011 Census, the Belgian communities, and public employment services. Age groups are divided into three categories: young (20-24 years), middle-aged (25-54 years) and older (55-64 years).

[3] The NBB dataset does not include public firms. Among private firms, financial companies are excluded. For a firm to be included in the dataset, it has to have at least one person employed, even in part-time.

[4] At the end of every calendar year, all VAT-liable firms in Belgium are required to fill a complete listing of their Belgian VAT-liable customers over that year. An observation in this data set refers to the sales value in euros of enterprise j selling to enterprise i within Belgium, excluding the VAT amount due on these sales. The reported value is the sum of invoices from j to i in a given calendar year. As every firm in Belgium is required to report VAT on all sales of at least 250 euros, the data has nearly universal coverage of all businesses active in Belgium (see Dhyne, Duprez, & Komatsu, 2023).

The CBSS database allows us to track individuals over time, providing insight into their employment status and the firms they work for. This enables us to calculate the total number of employees within firms each year and break this down by various characteristics, such as education and age. We can also track job changes, computing entries and exits: individuals are considered entrants if they start working at a firm in year t after being unemployed, inactive, or employed elsewhere in year $t-1$. Conversely, an exit occurs if an individual worked at a firm in year $t-1$ but not in year t. This detailed tracking allows for an in-depth analysis of workforce dynamics within firms over time.

3 Definition of digitalisation and descriptive statistics

To investigate the relationship between firm digitalisation and employment, we first define what constitutes a digitalised firm. Our definition relies on the NACE 4-digits classification of a firm's suppliers. We classify expenditures as digital if the supplier belongs to an industry aligned with definitions from Eurostat, UNCTAD, or criteria used by Dhyne *et al.* (2021) in their analysis of the same dataset. Appendix 1 summarises the NACE codes covered by our definition. All expenses to suppliers classified under these codes are labelled as digital expenditure; they are then tallied to obtain the total expenditure on digital goods and services. It is important to note that we have excluded suppliers of digital products from our sample, because, for these companies, we cannot distinguish whether ICT expenditure is intended for resale or whether it represents the digitalisation of the firm.

The most represented branches are computer activities (NACE codes 6201, 6202, 6203, 6209), which together account for 38% of digital expenditure on average over the studied period. These are followed by wholesale of computers and telecommunication equipment (codes 4651 and 4652), which constitutes 26% of digital expenditure, and retail sales of computers and telecommunication equipment (codes 4741 and 4742), making up 16%. Lastly, telecommunication activities (codes 6110, 6120, 6130 and 6190) represent 9% of digital expenditure. The remaining 11% is distributed across other branches, including the manufacture of electronics, computers, office machinery, publishing softwares and activities, data processing, web portals, and equipment repair services.

Due to data privacy constraints, the merged NBB-CBSS database does not include detailed information on the exact type of expense, only total digital expenditure, and the distinction between digital goods (NACE codes 2611 to 4742) and digital services (NACE codes 5821 to 9512). This distinction is important as we observe a shift over time, with proportionally more expenditures on ICT services – 63% in 2019 compared with 44% in 2003 – and less on ICT goods – 56% in 2003 compared with 37% in 2019.

Some of the literature on new technologies suggests that firms tend to make significant investments at certain points in time, leading to an estimation strategy that examines their employment or performance before and after such investment spikes. For example, studies on automation and robotics often focus on distinct adoption events (Acemoglu & Restrepo, 2020; Graetz & Michaels, 2018). However, when focusing on digital technologies – particularly information and communication technologies (ICT) – we do not observe such spikes in firms' expenses. Rather, ICT investments tend to be more gradual and continuous, reflecting an ongoing process of digitalisation (Bloom *et al.*, 2012). This continuous investment pattern necessitates a different approach to defining and measuring digitalisation, as set out in this paper.

As shown in Table 1, the share of ICT expenditure in total expenditure in year t is highly correlated with the share in year $t-1$, at 81%. This indicates a continuous investment process: firms that allocate a larger proportion of their expenditure to digital technologies tend to maintain this level of investment over the observed period. Furthermore, the maximum share of ICT expenditure per firm over the period is highly correlated (80%) with the firm's average share of ICT expenditure, excluding the maximum. This pattern holds true for periods surrounding the maximum share, with a high level of correlation observed from one to three years before and one to three years after the maximum. Similarly, the minimum share of ICT expenditure for a firm also shows substantial correlation, although to a lesser extent, at around 50% to 60%.

Table 1
Analysis of correlations with ICT expenditure

Correlation between firms' ICT share in t and t-1	0.809
Correlation between the maximum ICT share over the period and	
the average ICT share (excluding the maximum)	0.796
the ICT share the year before the maximum	0.804
the ICT share two years before the maximum	0.759
the ICT share three years before the maximum	0.732
the ICT share the year after the maximum	0.812
the ICT share two years after the maximum	0.763
the ICT share three years after the maximum	0.741
Correlation between the minimum ICT share over the period and	
the average ICT share (excluding the minimum)	0.633
the ICT share the year before the minimum	0.586
the ICT share two years before the minimum	0.539
the ICT share three years before the minimum	0.508
the ICT share the year after the minimum	0.596
the ICT share two years after the minimum	0.577
the ICT share three years after the minimum	0.561

This stylized fact influences our way to define digitalisation of a firm. Rather than an event study, we opt for a long-term definition. Firm digitalisation is defined as follows:

$$D_i = 1 \quad if \quad \forall t \;\; \delta_{i,t} > \tilde{\delta}_t, \;\; t \in \{2003, \ldots, 2019\}$$
$$D_i = 0 \; otherwise \qquad (1)$$

where $\delta_{i,t}$ is the share of digital expenditure by firm i in year t of its total expenditure, and $\tilde{\delta}_t$ is the median digital expenditure share for all firms in our sample in year t.

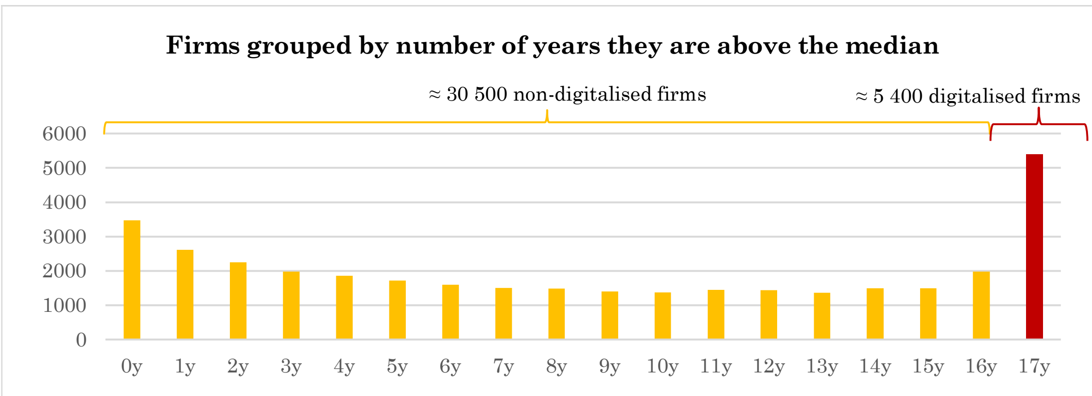
A firm is therefore considered digitalised if its share of digital expenditure over total expenditure is above the median every year. The median is almost constant over the years and is approximately 0.6% of total expenses. All other firms are labelled as non-digitalised.

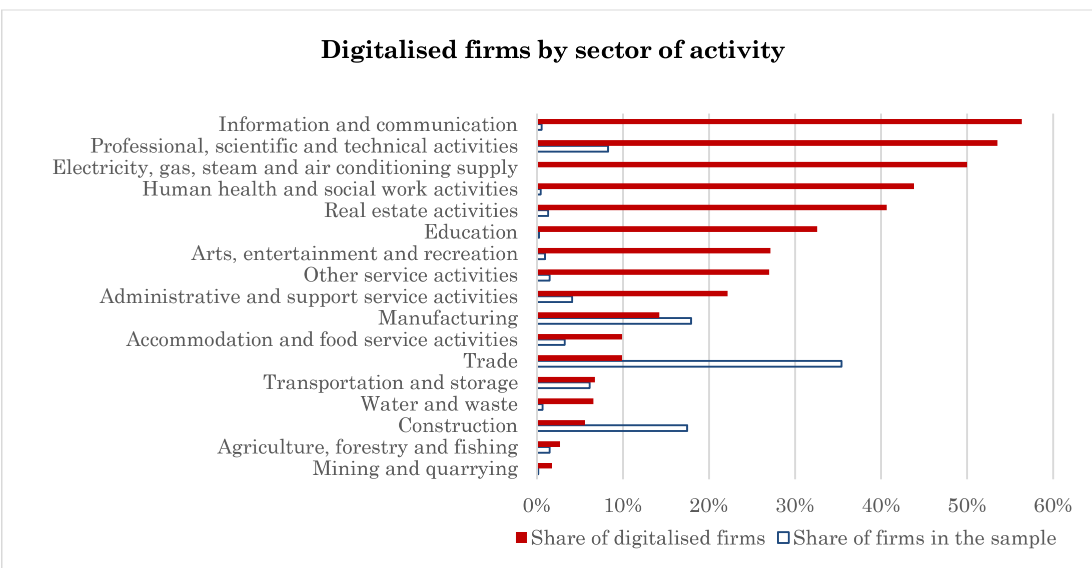
We focus exclusively on firms observed every year from 2003 to 2019. While this restricts our sample and the number of observations, it allows us to work in long differences and eliminates firm entries and exists, making our sample more homogenous. The resulting dataset includes

35,835 firms, representing on average 29% of private-sector firms active in Belgium over the period in question. In addition, it encompasses nearly one million workers, accounting for 53% of employment within private firms in the country.

Based on our definition and as shown in Figure 1, digitalised firms represent 15% of our sample, or 5,395 firms. In the rest of the distribution, firms appear equally distributed in terms of the number of years they are above the median, except for those that never digitalised or digitalised for only one or two years, which are more numerous. The share of digitalised firms varies considerably by sector of activity, ranging from 2% in the mining sector to 56% in information and communication. The most digitalised sectors are also those with a smaller share of firms in our sample, with the exception of professional, scientific and technical activities which represents 8% of our sample. The most represented sectors, i.e. manufacturing, trade, and construction, tend to have a lower share of digitalised firms (14%, 10% and 6%, respectively).

Figure 1 – Distribution of digitalised firms





In Table 2, we present descriptive statistics comparing digitalised versus non-digitalised firms, revealing several key differences between these two groups. First of all, digitalised firms have, on average, more employees than their non-digitalised counterparts. This was evident at the beginning of the period, with digitalised firms employing 53 people on average in 2003 compared with 17 for non-digitalised firms. This feauture persisted until the end of the period (67 employees in 2019 for digitalised firms against 22 for non-digitalised ones), although the employment growth rate was slightly lower in digitalised firms (26.4%) compared with non-digitalised firms (29.4%). Digitalised firms also seem to be more widespread around the average with a standard deviation almost four times higher than non-digitalised firms.

Table 2
Descriptive statistics: digitalised and non-digitalised firms

	Digitalised firms		Non-digitalised firms	
	2003	2019	2003	2019
Average number of employees	53	67	17	22
Standard deviation in number of employees	394	396	109	135
Total number of entries 2003-2019	218		59	
Total number of exists 2003-2019	204		55	
Share of low-educated workers	20%	13%	35%	23%
Share of middle-educated workers	42%	40%	43%	46%
Share of highly-educated workers	31%	35%	13%	16%
Share of young workers (20-24 years)	15%	7%	17%	7%
Share of middle-aged workers (25-54 years)	75%	73%	72%	68%
Share of older workers (55-64 years)	9%	21%	11%	25%

Digitalised firms also demonstrated greater dynamism over time, with a total of 218 new entries compared with 59 for non-digitalised firms, and 204 exits compared with 55. However, due to their larger size, the average employee turnover rate was similar between the two groups, at 41.5% for digitalised firms and 43.8% for non-digitalised ones.

In terms of workforce composition, digitalised firms had a significantly higher share of highly-educated workers—double that of non-digitalised firms. This share increased for both groups from 2003 to 2019. Conversely, the proportion of low-educated workers was much lower in digitalised firms and declined more slowly than in non-digitalised firms. The share of medium-educated workers was similar in 2003, but by 2019, non-digitalised firms had a higher proportion (46%) compared with digitalised firms (40%).

There are also notable differences in the age composition of the workforce. The share of older workers (55-64 years) increased significantly in both groups. In digitalised firms, it rose from 9% in 2003 to 21% in 2019, while in non-digitalised firms, it grew from 11% to 25%. Meanwhile, the share of middle-aged workers (25-54 years) remained relatively stable in digitalised firms, decreasing slightly from 75% to 73%, whereas non-digitalised firms experienced a more pronounced decline, from 72% to 68%. The proportion of young workers (20-24 years) dropped similarly in both groups, from 15% to 7% in digitalised firms and from 17% to 7% in non-digitalised firms.

These common trends, including a declining share of low-educated workers, a growing proportion of highly-educated workers, and a shift toward an older workforce, are partially reflective of broader demographic changes. People tend to be more educated over time. According to Labour Force Surveys from Eurostat, the proportion of individuals attaining tertiary education grew significantly, from 27% in 2003 to 39% in 2019. Conversely, people with at most a lower secondary degree represented 37% of the working age population in Belgium in 2003 but no more than 21% in 2019. The ageing population also became more pronounced during this period, with the share of people aged 55 and older in the working-age population increasing from 18% in 2003 to 23% in 2019.

These statistics highlight the differences in workforce composition and dynamics between digitalised and non-digitalised firms, suggesting that digitalisation is associated with larger, more dynamic firms that employ a higher proportion of highly-educated workers.

4 Methodology

To further analyse the link between digitalisation and employment within firms, we estimate the following baseline regression:

$$log(E_{i,2019}) - log(E_{i,2003}) = \alpha + \beta \, log(E_{i,2003}) + \gamma D_i + \eta s_i + \varepsilon_i \qquad (2)$$

where E_{i2019} is employment in firm i in 2019, E_{i2003} is employment in firm i in 2003, D_i is a binary variable taking the value of 1 if the firm is digitalised and 0 otherwise, s_i is a sector dummy, and ε_i is the error term.

In this regression, we analyse the variation in the logarithm of the number of workers within each firm over the studied period as a function of whether the firm is digitalised or not (as defined in Section 3, Equation 1). Since larger firms tend to have more stable employment levels compared to smaller firms (Davis *et al.*, 1996), we control for initial firm size by including the logarithm of the 2003 employment level. Employment growth rates vary significantly across industries, driven by diverse economic environments (market dynamics, regulation and policy, structural changes) and technological landscapes (including innovations not captured by our digitalisation measure).[5] To account for this, we also control for the firm's initial sector of activity at a detailed level (NACE 4-digits). Finally, our sample consists of firms that are all based in Belgium, active throughout the entire period (2003-2019), and operate in similar contexts, ensuring similarity between treated and control groups.

Taking all these controlling factors into account, our coefficient of interest, γ_1, measures the extent to which digitalised firms tend to grow faster in terms of the number of people employed compared with non-digitalised firms.

Throughout the paper, all regressions are estimated using both unweighted and weighted firms. In unweighted estimations, each firm is treated equally in the analysis, irrespective of its size or level of employment. This approach yields coefficients that reflect the average effect observed across all firms in the sample. In contrast, weighted estimations assign greater importance (or weight) to larger firms based on their average level of employment over the study period. By applying weights, the analysis emphasises the impact of larger firms more significantly in calculating aggregate coefficients. This allows us to derive results that are more representative of the economy as a whole, considering the influence of firms with higher employment levels. In sum, the unweighted estimations offer insights into the average impact

[5] See among others: Audretsch and Feldman (1996), Berman *et al.* (1994), Davis *et al.* (1996), Foster *et al.* (2006), Haltiwanger *et al.* (2013).

per firm, while the weighted estimations provide aggregated coefficients that extend to the broader economy.

5 Results

5.1 Digitalisation and net employment growth

Based on Equation 2, we examine the relationship between digitalisation and firm-level employment. The results, presented in Table 3, indicate a positive relationship between those two variables. Specifically, digitalised firms experienced about 19% higher employment growth from 2003 to 2019 compared with non-digitalised firms, holding the initial level of employment and the sector fixed effects constant. This is equivalent to an average annual employment growth of 1.1% across firms. Conversely, when we estimate Equation 2 by weighting firms according to their size, this percentage becomes 34% for the entire period, or 1.8% per year. This suggests that larger firms, which have more weigth in this specification, tend to have a stronger positive relationship between digitalisation and employment growth. This finding is further supported when dividing the sample into small and medium enterprises (following the OECD definition of less than 10 employees) and larger firms (10 or more employees). Digitalisation did not significantly impact SMEs' employment growth, but for firms with 10 or more employees in 2003, digitalisation was assoiated with a 39% higher employment growth over the period or a 2.1% higher rate annually (see Appendix 2).

Table 3
Baseline estimation of the relationship between digitalisation and employment

	(1)	(2)
Digitalisation	0.174***	0.291***
	(0.016)	(0.015)
Initial log of employment	-0.229***	-0.207***
	(0.004)	(0.004)
Constant	0.489***	1.149***
	(0.009)	(0.018)
Sector fixed effect	Yes	Yes
Firm size weights	No	Yes
Nb of observations	35,835	35,835
R^2	0.118	0.224

Note: (robust standard errors), *** p<0.01, ** p<0.05, * p<0.1.

The stronger effect of digitalisation on employment in larger firms can be attributed to several factors. Previous research has shown that larger firms are generally better positioned to leverage digital technologies in ways that foster employment growth. They benefit from economies of scale, greater resources, and more advanced digital strategies. In contrast, smaller firms tend to use digitalisation primarily for efficiency gains, which often does not lead to substantial job creation (Autor *et al.*, 2020; Gal *et al.*, 2019; DeStefano *et al.*, 2018; Akerman *et al.*, 2015).

To ensure that our results are not driven solely by high-performing firms, we conducted several robustness tests. While we cannot completely eliminate endogeneity issues (such as the possibility that growing firms are more likely to invest in digitalisation rather than digitalisation driving employment growth), our strategy helps reduce bias and provides greater insight into the factors driving these results.

In a first test, we split the sample into two subperiods keeping continously active firms over the period 2003-2019. We compute employment growth within firms during the period 2003-2010 and estimate the effect of digitalisation over the period 2011-2019, controlling for this prior growth trend. In this new specification, the link between digitalisation and employment growth remains positive and statistically significant (Table 4, Columns 1 and 2). Although the magnitude of the coefficient changes due to differences in time periods (16 years in the baseline and 8 years in this specification), the annualised effect shows a reduced unweighted impact (0.75% per year), indicating that the baseline result was partially driven by firms already growing rapidly between 2003 and 2010. However, the weighted results show a strong effect for larger firms, with an annualised impact of 1.89%, slightly higher than the baseline (1.84%). This suggests that digitalisation continues to benefit larger firms, even when controlling for past growth.

Table 4
Controlling for other firm characteristics

	Previous growth rate		Capital and productivity[1]		Reduced employment over the period[2]		Increased employment over the period[3]	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digitalisation	0.060***	0.151***	0.158***	0.202***	0.068***	0.260***	0.086***	0.129***
	(0.012)	(0.010)	(0.016)	(0.015)	(0.016)	(0.019)	(0.014)	(0.016)
Initial log of employment	-0.067***	-0.043***	-0.235***	-0.240***	-0.178***	-0.040***	-0.209***	-0.208***
	(0.003)	(0.003)	(0.005)	(0.006)	(0.004)	(0.005)	(0.004)	(0.004)
Initial log of capital			0.030***	0.044***				
			(0.004)	(0.005)				
Initial log of productivity[1]			0.249***	0.463***				
			(0.009)	(0.012)				
Log variation in employment 2003-2010	-0.017***	0.089***						
	(0.006)	(0.006)						
Constant	0.020***	0.102***	-2.598***	-4.458***	-0.270***	-0.589***	1.194***	1.756***
	(0.007)	(0.013)	(0.089)	(0.115)	(0.009)	(0.024)	(0.008)	(0.017)
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes	No	Yes	No	Yes
Nb of observations	35,835	35,835	34,009	34,009	18,450	18,450	17,335	17,335
R^2	0.045	0.132	0.148	0.255	0.145	0.237	0.194	0.290

Note: (robust standard errors), *** p<0.01, ** p<0.05, * p<0.1.
[1] Productivity is measured by the added value per worker.
[2] We keep only firms for which the level of employment in 2019 has decreased or remained constant compared with the level in 2003.
[3] We keep only firms for which the level of employment in 2019 is strictly higher than the level of employment in 2003.

High-performing firms can also have different initial level of capital and of productivity. When we add those two additional control variables in our specification (Table 4, Columns 3 and 4), the sign of the effect remains but the magnitude slightly decreases. Digitalised firms show an average 17% higher increase in employment over the period 2003-2019 compared with non-digitalised firms, which is slightly lower than the baseline estimation at 19%. Taking firm size into account, the effect is larger at 22% but reduced compared to the baseline (34%). Thus, the stronger relationship between digitalisation and employment in larger firms is partly driven by higher initial capital and productivity, though the positive effect persists after controlling for these factors.

Another approach to deepen the analysis of digitalisation's impact on employment is to split the sample into firms experiencing workforce contraction (or stable employment) and those experiencing expansion from 2003 to 2019. Digitalisation may affect firms differently based on their growth trajectory. For growing firms, digitalisation might accelerate job creation by enhancing efficiency, scaling operations, or accessing new markets. For shrinking firms, investing in ICT could act as a survival tool, helping to stabilize or slow their decline through productivity gains and cost reductions. However, it could also lead to job cuts, as automation and digital tools reduce the need for certain types of labour. Dividing the sample allows us to explore whether the positive effect of digitalisation is primarily driven by expanding firms or whether it benefits both shrinking and expanding firms.

The results show that for both groups, digitalisation has a positive and statistically significant effect on employment (Table 4, Columns 5 to 8). In the unweighted estimations, digitalised shrinking firms reduce employment by 7% less than non-digitalised shrinking firms, while expanding firms increase employment by 9% more than their non-digitalised counterparts. However, the weighted estimations reveal a more pronounced effect for shrinking firms, with a 30% reduction in job cuts, much higher than in the unweighted case. This suggests that larger shrinking firms significantly benefit from digitalisation, likely using it to stabilize or reorganize their operations. In contrast, for larger expanding firms, the effect of digitalisation remains positive but is smaller, at 14%, indicating that while digitalisation contributes to their growth, it may not be the primary or the only driver. These findings suggest that digitalisation plays a more crucial role in stabilizing struggling firms than in fueling the growth of expanding ones, where other factors may be more influential.

5.2 Robustness tests

To reinforce the validity of our findings, we conducted two important robustness tests. The first involves changing the period covered by our analysis. The second tests alternative definitions of what constitutes a digitalised firm.

We first conduct a series of estimations which entailed altering the period covered.[6] In this way, we verify that the results relate not only to the period covered by our data. Moreover, a more flexible time range means that the number of firms that survive for the entire period is larger and more representative of the economy.[7] The same holds true for the number of workers considered in our specifications. Panel A presents the impact of digitalisation on employment when the period covered is shortened by one year at the end and at the beginning, i.e. analysing the periods 2003-2018 and 2004-2019. Panel B explores the impact of digitalisation by splitting the period covered into two subperiods: 2003-2010 and 2011-2019. And Panel C further refines the analysis by dividing the period into three subperiods: 2003-2007, 2008-2013 and 2014-2019.

[6] Every time we adapt the study period, we calculate the new initial level of employment corresponding to the period in question.

[7] The period 2003-2018 covers 30% of private firms and 54% of employment. The period 2004-2019 covers 31% of private firms and 57% of employment. Dividing the period into two sub-periods increases the share of firms to 47% and 54%, respectively, for the first and the second period, and to 67% and 81% of employment. When the period is divided into three subperiods, the number of firms covered is 58%, 62% and 67% of total private firms in our dataset, respectively, and 74%, 82% and 93% of employment.

To ensure comparability with the baseline estimation, we present annual employment growth rates derived from the coefficients in Table 5. The estimated coefficient reflects the cumulative employment effect of digitalisation; however, shorter time frames naturally result in smaller coefficients. Therefore, calculating the annualised variation provides a more accurate measure.

Table 5
Robustness test – Changing the period covered

Panel A – Shortening the period covered by one year at the end and the beginning						
	2003-2018		2004-2019			
	(1)	(2)	(3)	(4)		
Digitalisation	0.158***	0.271***	0.157***	0.185***		
	(0.015)	(0.015)	(0.014)	(0.013)		
Initial log of employment	-0.225***	-0.203***	-0.217***	-0.164***		
	(0.004)	(0.004)	(0.004)	(0.003)		
Constant	0.467***	1.082***	0.449***	0.933***		
	(0.008)	(0.017)	(0.008)	(0.016)		
Sector fixed effect	Yes	Yes	Yes	Yes		
Firm size weights	No	Yes	No	Yes		
Nb of observations	37,763	37,763	38,920	38,920		
R^2	0.114	0.301	0.112	0.194		
Panel B – Splitting the period covered into two subperiods						
	2003-2010		2011-2019			
	(1)	(2)	(3)	(4)		
Digitalisation	0.099***	0.129***	0.076***	0.090***		
	(0.008)	(0.009)	(0.008)	(0.008)		
Initial log of employment	-0.163***	-0.121***	-0.147***	-0.077***		
	(0.003)	(0.002)	(0.002)	(0.002)		
Constant	0.312***	0.593***	0.242***	0.447***		
	(0.005)	(0.011)	(0.005)	(0.010)		
Sector fixed effect	Yes	Yes	Yes	Yes		
Firm size weights	No	Yes	No	Yes		
Nb of observations	58,458	58,458	67,302	67,302		
R^2	0.092	0.146	0.079	0.099		
Panel C – Splitting the period covered into three subperiods						
	2003-2007		2008-2013		2014-2019	
	(1)	(2)	(3)	(4)	(5)	(6)
Digitalisation	0.062***	0.086***	0.051***	0.072***	0.051***	0.051***
	(0.006)	(0.007)	(0.006)	(0.006)	(0.006)	(0.005)
Initial log of employment	-0.125***	-0.066***	-0.124***	-0.069***	-0.111***	-0.044***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)
Constant	0.224***	0.310***	0.172***	0.302***	0.180***	0.275***
	(0.004)	(0.008)	(0.004)	(0.008)	(0.004)	(0.008)
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes	No	Yes
Nb of observations	72,510	72,510	77,644	77,644	84,257	84,257
R^2	0.072	0.113	0.068	0.108	0.058	0.066

Note: (robust standard errors), *** p<0.01, ** p<0.05, * p<0.1.

Overall, the results remains very similar to the baseline, consistently showing a positive and statistically significant relationship between a firm's digitalisation and its employment growth, though the magnitude of the effect varies slightly.

In the unweighted estimations, the average annual impact of digitalisation on employment is around 1% across all periods. Nevertheless, a slightly larger effect is observed in earlier periods, with a 1.4% higher employment increase for digitalised firms between 2003 and 2010 compared with their non-digitalised counterparts, and a 1.6% annual effect for the period 2003-2007.

When firm size weights are added to the regressions, these findings are amplified. All estimations again show a positive link between digitalisation and employment, with a larger effect than in the unweighted estimations (except for the most recent period, 2014-2019). Notably, the further back in time we look, the stronger the effect of digitalisation. On an annual basis, digitalisation was associated with higher employment growth rates of 2.2% from 2003-2007, 1.5% from 2008-2013, and 1% from 2014-2019.

Our findings reinforce previous evidence that the impact of digitalisation on employment has been stronger in earlier periods compared to more recent years. This phenomenon is often attributed to the fact that in the earlier stages of digitalisation, firms were primarily adopting new technologies that brought significant efficiency gains, often leading to substantial job creation. However, over time, the effects may have become more muted as digitalisation has matured, and firms already operating with digital tools may see fewer additional employment gains from further technological integration.[8]

As a second robustness test, we apply alternative definitions of digitalisation to ensure that our results are not significantly influenced by the criteria used to define a digitalised firm. The results are summarised in Table 6.

Table 6
Robustness test – Definitions of digitalisation

	Control group "never digitalised"		Digital expenditure per worker		Digital goods		Digital services	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digitalisation	0.155***	0.259***	0.348***	0.539***	0.249***	0.442***	0.145***	0.226***
	(0.031)	(0.037)	(0.011)	(0.020)	(0.018)	(0.015)	(0.016)	(0.015)
Initial log of employment	-0.184***	-0.246***	-0.268***	-0.219***	-0.232***	-0.216***	-0.228***	-0.204***
	(0.008)	(0.007)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Constant	0.426***	1.477***	0.366***	0.826***	0.496***	1.161***	0.495***	1.160***
	(0.025)	(0.043)	(0.010)	(0.021)	(0.009)	(0.018)	(0.009)	(0.018)
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes	No	Yes	No	Yes
Nb of observations	8,817	8,817	35,835	35,835	35,835	35,835	35,835	35,835
R^2	0.121	0.370	0.138	0.231	0.120	0.235	0.117	0.220

Note: (robust standard errors), *** p<0.01, ** p<0.05, * p<0.1.

Previously, the control group consisted of firms not above the median share of ICT expenditure every year. This approach included firms that were never above the median and others that were sometimes above the median or that were almost always above the median, except for one year. We therefore test our regression by restricting the control group to firms that never digitalised over the period (i.e. were never above the median, as illustrated by firms with 0 year in Figure 1 of Section 3). This new definition significantly reduces our sample size to

[8] See Gal *et al.* (2019) and DeStefano *et al.* (2018)

8,817 firms. While the coefficients are slightly lower than in our baseline regression, they remain positive and statistically significant for both unweighted and weighted estimations[9].

In the second robustness test, we redefine digitalisation. Instead of using digital expenditure as a share of total expenditure, we calculate digital expenditure per employee and apply the same median-based definition (as defined in Equation 1 in Section 3). The results continue to show a positive and significant link between digitalisation and employment growth, with coefficients nearly double those of the baseline regression (Table 6, Columns 3 and 4). This new definition confirms that our findings do not solely depend on how ICT expenditure was calculated. However, its interpretation is less straightforward. A change in employment within a firm affects both the dependent variable (log variation in employment between 2003 and 2019) and the digitalisation definition, potentially creating feedback loops. It becomes challenging to determine whether ICT investment per worker drives employment changes, or if employment changes influence ICT intensity per worker. In contrast, our baseline definition did not directly depend on employment levels, allowing for a cleaner interpretation of the coefficients without the confounding influence of firm size.

To further explore the impact of digitalisation on employment growth, we analyse how different types of digital expenditure – specifically on digital goods and services – affect employment. This analysis is substantiated by our descriptive statistics, which reveal a significant shift in digital expenditure from goods to services over time (see Section 3).

We reformulate our definition of digitalisation considering separately ICT goods and ICT services, which are defined, respectively, as expenses classified under NACE codes 2611 to 4742 and NACE codes 5821 to 9512 (see Appendix 1). In the first specification, shown in Columns 5 and 6 of Table 6, a firm is classified as digitalised if its share of ICT goods expenditure relative to total expenditure exceeds the median share for the entire sample every year. Similarly, the second specification uses ICT services expenditure to compute a firm's share relative to the sample median (Columns 7 and 8 of Table 6).

The results indicate that both types of digital expenditure positively influence employment growth, but to varying degrees. Digitalisation through expenditure on digital goods demonstrates a strong positive relationship with employment growth. A firm investing in ICT goods has on average an 28% higher employment growth over the period 2003-2019 than its non-digitalised counterpart. In the weighted estimation, this effect doubles to 56%, confirming the importance of digitalisation in shaping employment in larger firms. These values are higher than our baseline results, suggesting that investment in digital goods may have a more substantial effect on employment growth than broader measure of digitalisation.

Conversely, expenditure on digital services reveals a positive and significant effect, though slightly lower, at 16% and 25%, respectively, for unweighted and weighted estimations. Given

[9] We also test by varying the number of years a firm must be above the median to be considered digitalised. Results are presented in Appendix 3. We regress the same equation but including, progressively, 16 years above the median, then 15 years, etc. The results still indicate that digitalisation increases the number of people employed within a firm. Nevertheless, for the unweighted estimations, the coefficient falls as we include more years in our definition, becomes statistically insignificant when digitalised firms are defined as those above the median for 3 years or more, and continues to be statistically insignificant for specifications of 2-17 years and 1-17 years. The results for weighted estimations are less clear with higher or lower coefficients which, however, always remain positive and statistically significant, indicating a positive relationship between firm digitalisation and the number of employees.

the observed shift from spending on digital goods to services over time, this could partly explain the reduced estimated impact of digitalisation in more recent periods. If this trend continues, we may see a moderation in the positive employment effects of digitalisation. However, emerging technologies such as artificial intelligence, which are not yet captured in our dataset, may alter these outcomes, as they are expected to significantly affect employment dynamics (Albanesi *et al.*, 2023).

5.3 Heterogeneity analyses

To deepen our understanding of the dynamic relationships underlying the observed positive association between firm digitalisation and employment growth, we conduct a series of sensitivity analyses. First, we examine the effects of digitalisation on workforce dynamics by analysing patterns of employees' entries and exits. This analysis provides insight into how digitalisation impacts not only overall employment levels, but also workforce stability and turnover within firms. While our baseline findings indicate a positive net increase in employment, this change could result from varying hiring and firing rates. Are digitalised firms attracting more employees or better retaining their workforce? Or do they tend to replace workers, firing those who are less adaptable and hiring individuals better suited to a digital environment?

This leads to a second question: What types of workers are digitalised firms employing? Depending on factors like education level or age, workers may be more or less likely to possess the skills needed in a digitalised firm—or more at risk of losing their jobs as firms transition to digital technologies. A net positive employment effect could obscure negative impacts for specific groups of workers.

Finally, firms may digitalise for different reasons or implement digitalisation differently based on their industry, which could influence its impact on employment. By distinguishing between sectors such as manufacturing, construction, trade, and professional services, we can assess whether the benefits of digitalisation are uniformly distributed or vary across industries.

These sensitivity analyses provide a more comprehensive understanding of the factors driving employment growth associated with digitalisation, offering a nuanced view of its implications for firms and their workforce.

5.3.1 Worker dynamics

In our baseline estimation (Equation 2), we observed that digitalisation was positively associated with net employment growth. However, this net variation masks the underlying dynamics of workforce changes, such as hiring (entries) and separations (exits). To gain deeper insights, we re-estimated our model, this time focusing separately on the total number of worker entries and exits over the period 2003-2019.

The following equations are used for our estimations:

$$log \sum_{t=2003}^{2019} N_{it} = \alpha + \beta\, log(E_{i,2003}) + \gamma D_i + \eta s_i + \varepsilon_i \qquad (3)$$

$$log \sum_{t=2003}^{2019} X_{it} = \alpha + \beta\, log(E_{i,2003}) + \gamma D_i + \eta s_i + \varepsilon_i \qquad (4)$$

where $\sum_{t=200}^{2019} N_{it}$ represents the total number of entries for firm i over the period and $\sum_{t=2003}^{2019} X_{it}$ represents the total number of exits. Other variables remain defined as in Equation 2.

The results reveal that digitalised firms experienced a 17% higher rate of worker entries than non-digitalised firms for an average firm (unweighted estimation). In the weighted estimation, the effect remains positive but slightly lower at 10%, suggesting more stable workforce dynamics among larger firms. Similarly, digitalised firms exhibit a higher rate of worker exits, with a 11% higher exit rate in the unweighted model and 4% in the weighted model, reflecting higher turnover in digitalised firms (Table 7).

Table 7
Digitalisation and entries/exits of workers

	Entries		Exits	
	(1)	(2)	(3)	(4)
Digitalisation	0.159***	0.095***	0.101***	0.039***
	(0.015)	(0.012)	(0.012)	(0.009)
Initial log of employment	0.757***	0.794***	0.825***	0.837***
	(0.004)	(0.003)	(0.003)	(0.002)
Constant	1.609***	2.222***	1.474***	1.962***
	(0.009)	(0.014)	(0.007)	(0.011)
Sector fixed effect	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes
Nb of observations	35,835	35,835	35,835	35,835
R^2	0.590	0.886	0.718	0.929

Note: (robust standard errors), *** p<0.01, ** p<0.05, * p<0.1.

These higher entry and exit rates among digitalised firms suggest greater labour market dynamism. They appear to have a more fluid workforce dynamics, characterised by both greater hiring and separation rates. The net employment growth observed in the baseline analysis is driven by this higher inflow of workers, although it is moderated by the corresponding higher rate of exits. This may suggest that digitalised firms are engaging in active workforce restructuring, potentially replacing lower-skilled roles with higher-skilled digital positions. To further explore this assumption, we will analyse in the next section how digitalisation influences workforce composition, focusing on the educational attainment and age of workers.

5.3.2 Workforce composition

The relationship between digitalisation and the composition of the workforce, particularly with regard to education levels, has been a key focus in the academic literature on the future of work. Numerous studies show that digitalisation tends to benefit more educated workers, as digital technologies complement cognitive and analytical skills typically associated with higher education. Conversely, it poses risks for those with less education, whose jobs are more susceptible to automation or whose do not have the necessary digital skills (Autor, 2015; Goos *et al.*, 2014; Brynjolfsson & McAfee, 2014).

Some studies have also explore how technological changes affect younger and older employees differently, given that age often correlates with digital skills, adaptability to new technologies, and job types. Research points out that digitalisation tends to benefit younger workers, who generally possess stronger digital skills and are more adaptable to technological changes. In contrast, older workers face greater risks of job displacement or may require re-skilling to remain competitive in increasingly digitalised work environments (Friedberg, 2003; Berger and Frey, 2016; Aisa *et al.*, 2023; Bessen *et al.*, 2023).

Our microdata on personal characteristics of workers provides a unique opportunity to measure how digitalisation influences the labour force composition within firms and contribute to this literature. To do so, we estimate the following equation for each specific characteristic x:

$$\frac{E_{i,2019}^{x}}{E_{i,2019}} - \frac{E_{i,2003}^{x}}{E_{i,2003}} = \alpha + \mu\left(\frac{E_{i,2003}^{x}}{E_{i,2003}}\right) + \beta \log E_{i,2003} + \gamma D_i + \eta s_i + \varepsilon_i \quad (5)$$

where $E_{i,t}^{x}$ is the number of employees in firm i with characteristic x in year t, and x is the level of educational attainment (i.e. low-educated, middle-educated, or highly-educated workers) or age group (i.e. young, middle-aged or older workers). Other variables remain defined as in Equation 2.

Equation 5 examines how the change in the share of characteristic x in total employment from the beginning to the end of the period is associated with digitalisation, while controlling for firm size, the initial share of employment for characteristic x and sector of activity at the 4-digit level. For instance, when characteristic x is low-educated workers, coefficient γ measures the extent to which the variation in the share of such workers within a firm is larger or smaller if the firm is digitalised compared with its non-digitalised counterpart.

The literature typically examines the impact of digitalisation on different types of workers by looking at the tasks associated with their jobs. However, our study leverages employer-employee microdata to directly observe changes in workforce composition within firms. This approach provides a unique and valuable perspective, allowing for a more precise measurement of how digitalisation influences the share of workers with varying levels of education and across different age groups. By using detailed microdata, our study contributes to a deeper understanding of the specific shifts in employment patterns induced by digitalisation, beyond the task-based analysis commonly found in existing research.

Table 8
Digitalisation and workforce composition

	Panel A – Level of education					
	Low-educated		Middle-educated		High-educated	
	(1)	(2)	(3)	(4)	(5)	(6)
Digitalisation	-0.0213***	-0.013***	-0.011**	0.003	0.039***	0.011***
	(0.004)	(0.002)	(0.005)	(0.002)	(0.004)	(0.002)
Initial log of employment	0.001	-0.004***	0.002	-0.002***	0.011***	0.008***
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)
Initial share of the respective level of education	-0.780***	-0.678***	-0.738***	-0.633***	-0.635***	-0.492***
	(0.005)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)
Constant	0.149***	0.141***	0.336***	0.299***	0.108***	0.087***
	(0.003)	(0.002)	(0.004)	(0.003)	(0.002)	(0.002)
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes	No	Yes
Nb of observations	35,835	35,835	35,835	35,835	35,835	35,835
R^2	0.477	0.511	0.380	0.352	0.306	0.307
	Panel B – Age group					
	Young (20-24)		Middle-aged (25-54)		Older (55-64)	
	(1)	(2)	(3)	(4)	(5)	(6)
Digitalisation	0.006**	-0.003***	0.029***	0.014***	-0.034***	-0.010***
	(0.002)	(0.001)	(0.005)	(0.002)	(0.005)	(0.002)
Initial log of employment	-0.001	0.000*	0.025***	0.007***	-0.020***	-0.007***
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Initial share of the respective age group	-0.911***	-0.829***	-0.941***	-0.926***	-0.799***	-0.800***
	(0.003)	(0.003)	(0.006)	(0.006)	(0.007)	(0.008)
Constant	0.058***	0.048***	0.593***	0.649***	0.263***	0.202***
	(0.001)	(0.001)	(0.005)	(0.005)	(0.003)	(0.003)
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes	No	Yes
Nb of observations	35,835	35,835	35,835	35,835	35,835	35,835
R^2	0.702	0.738	0.455	0.496	0.271	0.287

Note: (robust standard errors), *** p<0.01, ** p<0.05, * p<0.1.

As shown in the descriptive statistics, the share of low-educated workers tend to decline across all firms, while the representation of highly-educated workers rises. This reflects the broader trend of rising educational attainment, with more individuals now holding tertiary degrees compared to 20 years ago. Our results, summarised in Table 8 Panel A, suggest that this shift is even more pronounced in digitalised firms. Specifically, the share of low-educated workers is reduced by an additional 2 percentage points in digitalised firms, and the share of medium-educated falls by an additional 1 percentage point. In contrast, the share of highly-educated workers grows by 4 percentage points more in digitalised firms compared with non-digitalised firms. These effects are somewhat smaller when adjusting for firm size, consistent with the idea that larger firms tend to have more stable employment and lower turnover rates.

With regard to age groups, the descriptive statistics show a general increase in the share of older workers across all firms, reflecting population aging. However, the negative coefficient of digitalisation for older workers suggests that while firms are hiring more older workers overall, digitalised firms are hiring fewer older workers or are more likely to reduce their share through retirements, voluntary exits, or layoffs, as the demand for new skills rises. Conversely, the positive coefficient for middle-aged workers (aged 25–54) indicates that digitalised firms tend to prefer hiring workers in this age group, likely because they are perceived as having skills better aligned with digital technologies. The impact on younger workers is less clear, with a positive coefficient in the unweighted specification and a negative coefficient when controlling for larger firms, though the overall effect is close to zero (see Table 8 Panel B). In summary, digitalised firms are adjusting their workforce composition toward middle-aged workers, who are generally considered experienced yet adaptable to new technologies, at the expense of older workers.

To ensure that our results are not merely a reflection of the faster growth of digitalised firms, we re-estimate our regressions, adding the variation in the log of employment growth between 2003 and 2019 as a control variable. The results, presented in Appendix 4, continue to show a similar pattern, with a shift toward highly-educated and middle-aged workers in digitalised firms.

5.3.3 Sectoral analysis

Given the heterogeneity across sectors in the share of digitalised firms and the likely variation in how digitalisation is implemented within firms (see Figure 1 in Section 3), we conduct a sector-specific analysis focusing on the most represented sectors in the Belgian economy. We apply the same specification as in Equation 2 but split our sample by sector of activity. For each sector S, the following equation is estimated:

$$log(E_{i,2019}^{S}) - log(E_{i,2003}^{S}) = \alpha + \beta\, log(E_{i,2003}^{S}) + \gamma D_i + \eta s_i + \varepsilon_i \qquad (6)$$

where $E_{i,t}^{S}$ is employment in firm i in year t if the firm belongs to sector S in 2003. Other variables remain defined as in Equation 2. Notably, the definition of firm digitalisation is constructed based on the median for the entire sample and is not sector-specific. The results are summarised in Table 9.

In the manufacturing industry, we observe that digitalisation is strongly linked to employment increases, with a 21% rise in the unweighted estimation and a remarkable 68% in the weighted estimation. These coefficients exceed those found in our baseline results (19% and 34% respectively), indicating that the impact of digitalisation on employment is particularly pronounced in manufacturing, especially when larger firms are weighted more heavily.

Similarly, the services industry demonstrate a positive and significant relationship between digitalisation and employment growth is shown, with increases of 18% and 21% in unweighted and weighted estimations, respectively. Although these effects are slightly lower than those for the manufacturing industry, they still affirm the robust positive effect of digitalisation on employment. The consistent positive and significant coefficients across both sectors reinforce the overall conclusion that digitalisation contributes to employment growth. However, the differences in coefficient magnitude suggest that the effects are more substantial in the manufacturing industry, particularly for larger firms, than in services.

Table 9
Digitalisation and employment by sector of activity[1]

	Manufacturing		Services		Construction		Trade		Transport		Professional, scientific and technical activities	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Digitalisation	0.193***	0.518***	0.169***	0.192***	0.285***	0.291***	0.069**	-0.232***	0.257***	0.228***	0.184***	-0.087*
	(0.038)	(0.035)	(0.017)	(0.016)	(0.052)	(0.041)	(0.027)	(0.024)	(0.092)	(0.066)	(0.038)	(0.049)
Initial log of employment	-0.214***	-0.238***	-0.233***	-0.196***	-0.245***	-0.168***	-0.222***	-0.080***	-0.256***	-0.185***	-0.206***	-0.229***
	(0.009)	(0.010)	(0.005)	(0.004)	(0.010)	(0.009)	(0.007)	(0.005)	(0.018)	(0.017)	(0.016)	(0.013)
Constant	0.476***	1.085***	0.488***	1.205***	0.448***	0.773***	0.472***	0.734***	0.698***	1.060***	0.457***	1.6097***
	(0.025)	(0.052)	(0.010)	(0.018)	(0.020)	(0.031)	(0.014)	(0.023)	(0.045)	(0.066)	(0.032)	(0.056)
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Nb of observations	6,415	6,415	28,608	28,608	6,261	6,261	12,696	12,696	2,193	2,193	2,969	2,969
R^2	0.158	0.299	0.103	0.160	0.103	0.119	0.093	0.122	0.091	0.095	0.071	0.145

Note: (robust standard errors), *** p<0.01, ** p<0.05, * p<0.1.
[1] The manufacturing industry corresponds to NACE codes 10 to 33, the services sector includes NACE codes 41 to 96, and is further divided into construction (NACE codes 41 to 43), trade (NACE codes 45 to 47), transport (NACE codes 49 to 53) and professional, scientific and technical activities (NACE codes 69 to 75). Other sectors include too few firms to provide robust results.

Further analysis of the services industry reveals significant heterogeneity in the impact of digitalisation on employment growth. In the construction sector, digitalisation correlates with a 33% increase in employment (both unweighted and weighted), highlighting how this industry may leverage digital technologies to expand its workforce. Similarly, the transport sector shows positive effects, with increases of 29% and 26%, indicating that digitalisation supports workforce expansion in this industry as well.

Conversely, in trade and in professional, scientific, and technical activities, the impact of digitalisation is more nuanced. In the trade sector, the effect is only 7% and turns negative at -21% in the weighted estimation, suggesting that while smaller firms may benefit from digitalisation, larger firms could experience workforce reductions due to automation and efficiency gains. Likewise, in professional, scientific, and technical activities, the effect of digitalisation on employment is positive at 20% for the unweighted estimation but shifts to a negative -8% when firms are weighted by size.

This sectoral diversity suggests that the benefits of digitalisation are not uniform across the economy and may depend heavily on industry-specific dynamics. Further research are needed to better understand the mechanisms behind these differences, particularly how digitalisation interacts with industry characteristics and labour market conditions.

6 Conclusion

This study provides compelling evidence of the positive relationship between firm-level digitalisation and employment growth in Belgium from 2003 to 2019. Our findings reveal that digitalised firms experienced significantly higher employment growth compared to their non-digitalised counterparts, with an average annual increase of 1.1% across firms and 1.8% when accounting for firm size. This positive effect was particularly pronounced in larger firms, suggesting that they are better positioned to leverage digital technologies for job creation.

The positive impact of digitalisation on employment persists even when controlling for initial firm size, sector, capital, and productivity levels. This effect is observed in both expanding and contracting firms, with digitalisation appearing to play a crucial role in stabilizing employment in struggling firms. The positive effect of digitalisation on employment appears to be stronger in earlier periods of our study, suggesting that as digitalisation matures, its impact on job creation may moderate. This could also be due to the shift from digital goods to digital services between 2003 and 2019, the latter showing a smaller effect on employment.

Digitalised firms demonstrate greater workforce dynamism, with higher rates of both worker entries and exits. This suggests that digitalisation is associated with active workforce restructuring, potentially replacing lower-skilled roles with higher-skilled digital positions. This last finding is confirmed by our analysis of the workforce composition. Digitalised firms show a more pronounced increase in the share of highly-educated workers and a larger decrease in the share of low-educated workers. They also tend to favor middle-aged workers (25-54 years) over older workers (55-64 years).

The impact of digitalisation varies across sectors. While generally positive, the effect is particularly strong in manufacturing and certain service industries like construction and transport. However, in trade and professional services, the impact is more nuanced, with potential negative effects for larger firms.

These findings have important implications for policymakers and business leaders. They suggest that promoting digitalisation could be an effective strategy for job creation and economic growth. However, the varying impacts across different types of workers and sectors highlight the need for targeted policies to ensure that the benefits of digitalisation are broadly shared. This could include initiatives to support the digital transformation of small and medium enterprises, programs to reskill and upskill workers (particularly older and less educated workers), and sector-specific strategies to maximize the positive employment effects of digitalisation.

It's important to note the limitations of our study. While we observe a strong positive correlation between digitalisation and employment growth, we cannot definitively establish causality due to potential endogeneity issues. Firms that choose to digitalise may have other characteristics that predispose them to faster growth. Future research could address this by employing instrumental variable approaches or exploiting natural experiments to isolate the causal effect of digitalisation on employment.

Moreover, our study focuses on the period up to 2019 and does not capture the potential impacts of more recent technological advancements, such as artificial intelligence, which may significantly alter the relationship between digitalisation and employment. Future studies could extend this analysis to include these newer technologies and examine their effects on workforce dynamics.

Additionally, while our study provides valuable insights into the quantitative aspects of employment changes, further research could explore the qualitative dimensions of these shifts. This could include investigating changes in job roles, skill requirements, and working conditions, particularly wages, associated with digitalisation.

In conclusion, our findings contribute to the ongoing debate about the future of work in the digital age. They suggest that, at least in the context of Belgium from 2003 to 2019, digitalisation has been associated with net job creation rather than job destruction. However, the uneven distribution of these benefits across worker groups and sectors underscores the need for thoughtful policies to ensure that the digital transformation of the economy promotes inclusive growth and employment opportunities for all.

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Appendices

Appendix 1 – Definition of ICT expenditure

NACE	**Description**	**Sources**		
		Eurostat	**UNCTAD**	**Dhyne *et al.* (2021)**
2611	Manufacture of electronic components	x	x	
2612	Manufacture of loaded electronic boards	x	x	
2620	Manufacture of computers and peripheral equipment	x	x	x
2630	Manufacture of communication equipment	x	x	x
2640	Manufacture of consumer electronics	x	x	
2651	Manufacture of instruments and appliances for measuring, testing and navigation		x	
2670	Manufacture of optical instruments and photographic equipment		x	
2680	Manufacture of magnetic and optical media	x	x	
2823	Manufacture of office machinery and equipment		x	
2931	Manufacture of electrical and electronic equipment for motor vehicles		x	
4651	Wholesale of computers, computer peripheral equipment and software	x		x
4652	Wholesale of electronic and telecommunications equipment and parts	x		x
4741	Retail sale of computers, peripheral units and software in specialised stores			x
4742	Retail sale of telecommunications equipment in specialised stores			x
5821	Publishing of computer games	x		
5829	Other software publishing	x	x	x
5911	Motion picture, video and television programme production activities		x	
5920	Sound recording and music publishing activities		x	
6110	Wired telecommunication activities	x		x
6120	Wireless telecommunications activities	x		x
6130	Satellite telecommunications activities	x		x
6190	Other telecommunications activities	x		x
6201	Computer programming activities	x		x
6202	Computer consultancy activities	x		x
6203	Computer facilities management activities	x		x
6209	Other information technology and computer service activities	x		x
6311	Data processing, hosting and related activities	x		x
6312	Web portals	x		x
9511	Repair of computers and peripheral equipment	x		
9512	Repair of communication equipment	x		

Appendix 2 – Baseline regression dividing firms by size

In this table, we conduct the same analysis as in the baseline regression but dividing the sample of firms into two main categories: small and medium enterprises (less than 10 employees in 2003) and large firms (10 employees or more in 2003).

	Less than 10 employees in 2003		10 employees or more in 2003	
	(1)	(2)	(3)	(4)
Digitalisation	0.140***	-0.011	0.204***	0.328***
	(0.019)	(0.024)	(0.028)	(0.025)
Initial log of employment	-0.441***	-0.590***	-0.086***	-0.202***
	(0.008)	(0.011)	(0.011)	(0.007)
Constant	0.668***	1.513***	0.117***	1.141***
	(0.010)	(0.017)	(0.036)	(0.039)
Sector fixed effect	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes
Nb of observations	24,381	24,381	11,410	11,410
R^2	0.147	0.252	0.099	0.236

Note: (robust standard errors), *** p<0.01, ** p<0.05, * p<0.1.

Appendix 3 – Robustness test on the definition of a digitalised firm

In this analysis, we gradually change the definition of a digitalised firm by relaxing the condition of the number of years a firm is above the median share of digital expenditure.

	16-17 years above the median		15-17 years above the median		14-17 years above the median	
	(1)	(2)	(3)	(4)	(5)	(6)
Digitalisation	0.129***	0.285***	0.133***	0.283***	0.123***	0.294***
	(0.014)	(0.014)	(0.013)	(0.014)	(0.013)	(0.014)
Initial log of employment	-0.228***	-0.206***	-0.228***	-0.206***	-0.228***	-0.205***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Constant	0.486***	1.128***	0.481***	1.118***	0.477***	1.010***
	(0.009)	(0.018)	(0.009)	(0.018)	(0.009)	(0.018)
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes	No	Yes
Nb of observations	35,835	35,835	35,835	35,835	35,835	35,835
R^2	0.117	0.224	0.117	0.224	0.117	0.225
	13-17 years above the median		12-17 years above the median		11-17 years above the median	
	(7)	(8)	(9)	(10)	(11)	(12)
Digitalisation	0.106***	0.231***	0.097***	0.220***	0.079***	0.164***
	(0.012)	(0.014)	(0.012)	(0.014)	(0.011)	(0.014)
Initial log of employment	-0.227***	-0.200***	-0.226***	-0.198***	-0.226***	-0.195***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Constant	0.476***	1.098***	0.475***	1.090***	0.477***	1.098***
	(0.009)	(0.018)	(0.010)	(0.018)	(0.010)	(0.018)
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes	No	Yes
Nb of observations	35,835	35,835	35,835	35,835	35,835	35,835
R^2	0.117	0.221	0.116	0.221	0.116	0.218
	10-17 years above the median		9-17 years above the median		8-17 years above the median	
	(13)	(14)	(15)	(16)	(17)	(18)
Digitalisation	0.068***	0.050***	0.064***	0.074***	0.054***	0.078***
	(0.011)	(0.014)	(0.011)	(0.014)	(0.011)	(0.014)
Initial log of employment	-0.225***	-0.188***	-0.225***	-0.189***	-0.224***	-0.189***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Constant	0.478***	1.131***	0.476***	1.120***	0.478***	1.115***
	(0.010)	(0.018)	(0.010)	(0.019)	(0.010)	(0.019)
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes	No	Yes
Nb of observations	35,835	35,835	35,835	35,835	35,835	35,835
R^2	0.116	0.215	0.116	0.216	0.115	0.216

Note: (robust standard errors), *** p<0.01, ** p<0.05, * p<0.1.

	7-17 years above the median		6-17 years above the median		5-17 years above the median	
	(19)	(20)	(21)	(22)	(23)	(24)
Digitalisation	0.048***	0.050***	0.041***	0.061***	0.030***	0.047***
	(0.011)	(0.014)	(0.011)	(0.015)	(0.012)	(0.015)
Initial log of employment	-0.224***	-0.188***	-0.224***	-0.188***	-0.223***	-0.187***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Constant	0.479***	1.124***	0.480***	1.117***	0.485***	1.122***
	(0.011)	(0.019)	(0.011)	(0.019)	(0.011)	(0.020)
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes	No	Yes
Nb of observations	35,835	35,835	35,835	35,835	35,835	35,835
R^2	0.115	0.215	0.115	0.216	0.115	0.215

	4-17 years above the median		3-17 years above the median		2-17 years above the median	
	(25)	(26)	(27)	(28)	(29)	(30)
Digitalisation	0.022*	0.082***	0.009	0.157***	0.014	0.139***
	(0.012)	(0.015)	(0.013)	(0.017)	(0.014)	(0.018)
Initial log of employment	-0.223***	-0.188***	-0.223***	-0.191***	-0.223***	-0.189***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Constant	0.489***	1.096***	0.497***	1.042***	0.492***	1.043***
	(0.012)	(0.020)	(0.013)	(0.021)	(0.015)	(0.023)
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes	No	Yes
Nb of observations	35,835	35,835	35,835	35,835	35,835	35,835
R^2	0.115	0.216	0.115	0.217	0.115	0.216

	1-17 years above the median	
	(31)	(32)
Digitalisation	0.013	0.063***
	(0.018)	(0.023)
Initial log of employment	-0.223***	-0.186***
	(0.004)	(0.004)
Constant	0.493***	1.093***
	(0.018)	(0.027)
Sector fixed effect	Yes	Yes
Firm size weights	No	Yes
Nb of observations	35,835	35,835
R^2	0.115	0.215

Note: (robust standard errors), *** p<0.01, ** p<0.05, * p<0.1.

Appendix 4 – Robsutness test on workforce composition

In this specification, we estimate Equation 5 but adding the employment growth of the firm over the period as an additional control variable.

	Panel A – Level of education					
	Low-educated		Middle-educated		High-educated	
	(1)	(2)	(3)	(4)	(5)	(6)
Digitalisation	-0.023***	-0.017***	-0.017***	-0.005**	0.037***	0.015***
	(0.004)	(0.002)	(0.005)	(0.002)	(0.004)	(0.002)
Initial log of employment	0.003***	-0.001	0.011***	0.003***	0.014***	0.004***
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Initial share of the respective level of education	-0.777***	-0.662***	-0.741***	-0.636***	-0.637***	-0.478***
	(0.005)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)
Log of employment in 2019 – log of employment in 2003	0.012***	0.016***	0.040***	0.025***	0.012***	-0.016***
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
Constant	0.142***	0.118***	0.318***	0.272***	0.102***	0.103***
	(0.003)	(0.003)	(0.004)	(0.003)	(0.002)	(0.002)
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes	No	Yes
Nb of observations	35,835	35,835	35,835	35,835	35,835	35,835
R^2	0.478	0.521	0.391	0.372	0.308	0.319
	Panel B – Age groups					
	Young (20-24y)		Middle-aged (25-54y)		Old (55-64)	
	(1)	(2)	(3)	(4)	(5)	(6)
Digitalisation	0.003	-0.005***	0.015***	0.002	-0.017***	0.004**
	(0.002)	(0.001)	(0.005)	(0.002)	(0.005)	(0.002)
Initial log of employment	0.003***	0.002***	0.044***	0.016***	-0.043***	-0.018***
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Initial share of the respective age group	-0.913***	-0.831***	-0.946***	-0.920***	-0.822***	-0.809***
	(0.003)	(0.003)	(0.006)	(0.005)	(0.007)	(0.008)
Log of employment in 2019 – log of employment in 2003	0.017***	0.008***	0.082***	0.041***	-0.097***	-0.049***
	(0.001)	(0.000)	(0.002)	(0.001)	(0.002)	(0.001)
Constant	0.050***	0.039***	0.556***	0.598***	0.314***	0.259***
	(0.002)	(0.001)	(0.005)	(0.005)	(0.003)	(0.003)
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm size weights	No	Yes	No	Yes	No	Yes
Nb of observations	35,835	35,835	35,835	35,835	35,835	35,835
R^2	0.706	0.742	0.490	0.540	0.340	0.376

Sources: CBSS, NBB, author's computations.
Note: (robust standard errors), *** p<0.01, ** p<0.05, * p<0.1

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