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# THE IMPACT OF DIGITALISATION ON PRODUCTIVITY: FIRM-LEVEL EVIDENCE FROM THE NETHERLANDS

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Colombia was not an OECD member at the time of preparation of this paper. Accordingly, Colombia is not included in the list of OECD countries and is not included in the area totals.

# ABSTRACT / RESUME


## The impact of digitalisation on productivity: Firm-level evidence from the Netherlands

This paper analyses the role of intangibles and digital adoption for firm-level productivity in the Netherlands drawing on a newly constructed panel data set of Dutch enterprises. It provides robust evidence on productivity effects of intangibles and digital adoption using firms' exposure to sector-wide advances in intangible intensity and digital adoption as an instrument. Results show that intangibles as measured by levels of digital skill intensity have a positive and statistically significant impact on firm-level productivity growth in the service sector and for younger firms. Productivity benefits from software investment are strong for low productivity firms. Together, these findings highlight the potential of intangibles to support the productivity catch-up of laggard enterprises. The evidence also suggests that productivity benefits from ICT hardware investment and the uptake of high-speed broadband are positive and sizeable.



*JEL classification codes*: D24; E22; J24; O33

*Keywords*: digitalisation, intangibles, productivity, skills


This Working Paper relates to the 2021 OECD Economic Survey of the Netherlands (https://oe.cd/nld)

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## L'impact de la numérisation sur la productivité: Une analyse sur données des entreprises aux Pays-Bas

Cet article analyse le rôle des actifs immatériels et de l'adoption du numérique pour la productivité des entreprises aux Pays-Bas exploitant des données de panel. Les résultats montrent que les actifs immatériels mesurés par les niveaux de l'intensité des compétences numériques ont un impact positif et statistiquement significatif sur la croissance de la productivité des entreprises dans le secteur des services et pour les entreprises plus récentes. Les avantages de la productivité des investissements logiciels sont importants pour les entreprises à faible productivité. Ensemble, ces résultats mettent en évidence le potentiel des actifs immatériels pour soutenir le rattrapage de la productivité des entreprises à la traîne. Les données probantes suggèrent également que les avantages de la productivité découlant des investissements en matériel informatique et de l'utilisation d'Internet à haut débit sont positifs et appréciables.



*Classification JEL*: D24; E22; J24; O33

*Mots Clés*: numérisation, actifs immatériels, productivité, compétences


Ce Document de travail a trait à l'Étude économique de l'OCDE des Pays-Bas, 2021 (https://oe.cd/nld)

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# The impact of digitalisation on productivity: Firm-level evidence from the Netherlands

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## 1. Introduction

1. The potential of digital transformation to boost productivity and living standards is vast. Digital technologies give firms new tools to design, produce and sell goods and services, and provide individuals with new ways for social and economic interactions. Technology adoption and improved digital skills have the potential to increase the contribution of capital and labour to productivity and growth. The Netherlands is in a good position to reap the potentials of digitalisation based on its low regulatory barriers to competition and its well-educated workforce (OECD, 2021). Yet despite ongoing digitalisation, as in other advanced economies, productivity growth in the Netherlands has been sluggish over the past decade – measured both in terms of multifactor productivity and in terms of labour productivity.

2. This productivity paradox is nothing new. Already in 1987, Robert Solow famously stated, "you can see the computer age everywhere but in the productivity statistics" in reference to the productivity slowdown of the 1970s and 1980s despite the rapid development of information technologies. The productivity paradox came to the forefront again when productivity growth slowed around 2005 and remained low to the present day. Some authors have voiced concerns that digital technologies have had only a transitory impact on productivity and will not alter long-term living standards fundamentally. For the Netherlands, for instance, Grabska *et al.* (2017) suggest that the recent productivity slowdown may reflect a return to normal after strong productivity growth on the back of the ICT revolution between 1995 and 2004. This is in line with Gordon (2012), who predicts that digital technologies are less transformative than previous waves of technological change.

3. Other authors point to the yet untapped potential of digital technologies and argue that the recent productivity slowdown mirrors a transition period in which some firms are still learning to use them. OECD work (Andrews *et al.*, 2016) shows that the aggregate productivity slowdown reflects weaker productivity

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growth of laggard firms – excluding the top 5% of companies with the highest productivity (or frontier firms). By contrast, productivity growth of frontier firms has been strong across many OECD economies, suggesting weaker technology diffusion from the "best to the rest". For the Netherlands, recent research does not confirm productivity divergence, but rather shows that the productivity frontier is characterised by strong entry and exit (Van Heuvelen *et al.*, 2018). Strong entry and exit dynamics suggests that technology diffusion enables most productive firms to catch up to the productivity frontier.

4. Digital technologies such as big data, cloud computing, and improved front-office operations that reduce costs of interacting with suppliers and customers are shown to bring productivity benefits. For instance, recent OECD evidence shows that a 10 percentage point increase in the sector-wide adoption rate of cloud computing is associated with a 3.5% productivity increase for the average European firms after five years (Gal *et al.*, 2019). Furthermore, complementary investment in skills and factors such as software and data, important parts of many firm's intangible capital, may be necessary to reap the benefits of digitalisation (e.g. van Ark, 2016; Brynjolfsson and McAfee, 2011). Digital skill use at work is essential, and includes computer use skills and specialist ICT skills, such as those of programmers (OECD, 2019). Firms may also need to reorganise their business models around intangible assets to seize their productivity potential (Haskel and Westlake, 2019; Brynjolfsson *et al.*, 2007). In contrast to physical capital, intangibles can be scaled-up easily at low costs and allow firms to grow rapidly. Studies show that firms that spend the most on intangible assets have the strongest productivity growth (see e.g. Crouzet and Eberly, 2018), and intangibles are found to support the translation of technology into improved productivity (Mohnen, Polder and van Leeuwen, 2018; Corrado, Haskel and Jona-Lasinio, 2017). Furthermore, firms in digital-intensive sectors fall behind in terms of productivity if they are unable to carry out the necessary investment in intangibles (Criscuolo and Himbert, 2021). These positive findings notwithstanding, there is little prior evidence on the impact of the newest wave of digital technologies, investment in software, and digital skill use at work on firm-level productivity in the Netherlands.

5. This paper presents firm-level evidence on the relationship between labour productivity, the adoption of concrete digital technologies, software investments, and the availability of skills in the Netherlands. The analysis builds on a unique dataset of Dutch enterprises that covers service sector and manufacturing firms, and is, to the authors' knowledge, the first paper to investigate the link between productivity, the adoption of digital technologies, software investment, and the availability of skills in the Dutch context. It takes a broader view on intangibles than Mohnen *et al.* (2018) by including software investments and digital skill use at work.

6. The empirical approach is based on recent OECD work on productivity and digitalisation, notably Mosiashvili and Pareliussen (2020), Gal *et al.* (2019), and Sorbe *et al.* (2019), and departs from an endogenous growth model of technology diffusion. Following state-of-the-art empirical literature, the paper uses an instrumental variable strategy to estimate causal effects of digital adoption, software investment and digital skill use at work on productivity growth of non-frontier firms (see e.g. Acemoglu and Restrepo, 2020; Cette *et al.*, 2020). The instrumental variable measures firm-level exposure to sector-wide technology advances and intangible intensity, and is derived from lagged firm-level adoption and intangible intensity and sector-wide means of digital adoption and intangible intensity. The identification rests on the assumption that firms in sectors with higher digital adoption or intangible intensity are not affected by other productivity shocks or trends that simultaneously affect digitalisation and productivity. For instance, while industries exposed to skill shortages could respond with both higher digital adoption and productivity, tests indicate that the exposure variable is not affected by such sector-wide developments.

7. The findings show that digital skill use at work has a positive and statistically significant impact on firm-level labour productivity growth in services and younger firms. Productivity benefits from software investment are strong for low productivity firms. Together, these results point to the potential of intangibles to support the productivity catch-up of laggards, and suggest that increasing intangible intensity among laggard enterprises can help moving their productivity performance closer to the frontier. Finally, the

findings show that firm-level productivity benefits from ICT hardware investment and high-speed broadband are positive and sizeable.

8. The COVID-19 shock and associated mobility restrictions appear to have further boosted the use of digital technologies by firms. This study does not cover the period of the COVID-19 crisis, but the findings suggest that significant productivity improvements can be expected on the back of an accelerated pace of digital adoption. This assumes that low productivity firms have the necessary capacities to adopt digital technologies. Otherwise, the crisis might lead to increased inequality among firms. Furthermore, any positive effects will likely be outweighed by negative impacts of the pandemic outside the scope of this paper, notably reduced skill accumulation, bankruptcies, and elevated unemployment.

9. The remainder of the paper is structured as follows: The next section describes the data and the empirical methodology. The third section presents empirical results, before the fourth section discusses the main results and concludes.

## 2. Data and methodology

### *2.1 Data and variables*

10. The analysis is based on business survey data from Statistics Netherlands (Table 1). The sample of Dutch enterprises consists of 10 289 firms with 10 or more employees that are covered by the production and investment surveys and that have participated in the Community Survey on ICT Usage between 2012 and 2017. The unbalanced panel contains detailed firm-level information on value added, fixed assets and employment, which are needed to construct measures of labour productivity and multifactor productivity (MFP). The final sample for the analysis consists of 3 279 firms since not all firms have the necessary information on productivity available.

11. The data also provide rich information on digital and intangible variables, including on digital infrastructure such as the share of ICT hardware investment in total fixed assets (ICT hardware investment) and whether the enterprise has a high-speed broadband connection with at least 30 Mbit/s (high-speed broadband). Further, the data contain information on firm-level intangible capital, as measured by the share of investments in software in total investments, and different digital skills used at Dutch enterprises. The latter entails the share of ICT specialists in the total workforce (ICT specialist skills), the share of software specialists in the total workforce (software specialist skills), the share of workers using computers for work purposes (computer use at work), and whether the firm has offered ICT training to its employees. It should be noted that the proxies used for intangibles do not fully capture the whole range of intangibles and digital skills. Intangibles are much broader than software alone, and include, among others, organisational capital, management skills, and research and development. In addition, digital skills are measured by formal employment in ICT and software jobs, whereas ICT skill levels of workers as such are not captured except through in-house training.

12. Furthermore, the data provide information on firm adoption of several specific digital technologies, including the more recent technologies of cloud computing and big data analytics. Information on the latter is available for the most recent years 2015 to 2017 only. It also covers whether firms use front-office software for Customer Relationship Management (CRM) and Enterprise Resource Planning (ERP). As mentioned above, software investment and ICT hardware investment are deflated separately using gross fixed capital formation deflators from Eurostat National Account Statistics. In addition, the panel data permit accounting for differences across industries and firm segments, including frontier versus laggard firms, firm size, sector and age. The digital and intangible variables are correlated, which may related to underlying complementarities arising, for instance, from their joint adoption. However, the degree level of correlation is low, which allows testing their joint effects (Table A.1 in Annex A).

## Table 1. Description of variables

| Variable | Description | Level | Coverage | Statistic Netherlands source |
|---|---|---|---|---|
| **Dependent variable** | | | | |
| **Labour productivity growth** | The change in the natural logarithm of labour productivity calculated as real value added divided by the number of employees | Enterprise | 2012-2017 | Production survey |
| **Multifactor productivity[1] growth** | The change in the natural logarithm of MFP | Enterprise | 2012-2017 | Production and investment survey |
| **Control variables** | | | | |
| **Frontier growth** | Average change in the natural logarithm of labour productivity of the top 5 percent firms in each sector-year cell | Sector | 2012-2017 | Production survey |
| **Gap to frontier** | Lagged distance to the frontier (based on log labour productivity levels) | Enterprise | 2012-2017 | Production survey |
| **Capital per worker** | Natural logarithm of real total fixed assets (excl. ICT and software) as derived from investment figures divided by number of employees | Enterprise | 2012-2017 | Investment survey |
| **Firm age** | Firm age calculated as the difference between the current year and the year of establishment | Enterprise | 2012-2017 | Business demography |
| **Firm size** | Dummy indicators for firm size computed by the number of employees as small (10-49 employees), medium (50-249 employees), and large (250+ employees) enterprises | Enterprise | 2012-2017 | Production survey |
| **Sectoral ICT skill shortages** | Share of enterprise with vacancies for IT specialists who were difficult or impossible to fill | Sector | 2013-2017 | ICT survey |
| **Digital and intangible variables** | | | | |
| ***ICT infrastructure*** | | | | |
| **ICT hardware investment** | Share of real ICT hardware investment in real total fixed assets | Enterprise | 2012-2017 | Investment survey |
| **High-speed broadband** | Dummy variable = 1 if the maximum contracted download speed of the fastest internet connection is at least 30 Mbit/s | Enterprise | 2012-2017 | ICT survey |
| **Intangibles including skills** | | | | |
| **Software investment** | Share of real software investment in real total fixed assets | Enterprise | 2012-2017 | Investment survey |
| **ICT specialist skills** | Share of ICT specialists in total employees | Enterprise | 2012-2017 (2016 missing) | ICT survey |
| **Software specialist skills** | Share of ICT specialists for software development in total employees | Enterprise | 2012-2017 (2016 missing) | ICT survey |
| **Computer use at work** | Share of employees that use computers for business purposes in total employees | Enterprise | 2012-2017 | ICT survey |
| **ICT training** | Dummy variable = 1 if the enterprise has provided ICT training for its employees. | Enterprise | 2013-2017 (2016 missing) | ICT survey |
| **Digital technologies** | | | | |
| **CRM/ERP front-office software** | Dummy variable = 1 if the enterprise has used Customer Relationship Management (CRM) or Enterprise Resource planning (ERP) software package to share information between different functional areas | Enterprise | 2012-2017 | ICT survey |
| **Cloud computing** | Dummy variable = 1 if the enterprise has paid for cloud services | Enterprise | 2013, 2015, 2017 | ICT survey |
| **Big data analytics** | Dummy variable = 1 if the enterprise has conducted big data analysis (employees analyse themselves or other company conducts the analysis) | Enterprise | 2015-2017 | ICT survey |
| **Sectors and firm segments** | | | | |

| | | | | |
|---|---|---|---|---|
| **Manufacturing/ services** | Dummy indicators of firms belonging to manufacturing (NACE Rev.2 10-33) or services (NACE Rev.2 45-82). | Enterprise | 2012-2017 | Production survey |
| **Young/ incumbent firm** | Dummy indicators computed by firm age as young (established in 2009 of after) and incumbent (before 2009) | Enterprise | 2012-2017 | Production survey |
| **Digital-intensive sector[2]** | Dummy variable = 1 if the enterprise belongs to a digital-intensive sector (NACE Rev.2 29-30, 61-63, 69-75 and 77-82) | Sector | 2012-2017 | Production survey |

Note: [1] Multifactor productivity (MFP) is based on the Wooldridge (2009) methodology. [2] Digital-intensity is based on methodology by Calvino *et al*. (2018). Variables are calculated for the sample of non-frontier firms (top 5 percent firms in each sector-year cell), except for the frontier growth variable.

13. The economic analysis of the data requires processing and cleaning of the business survey information. First, nominal value added and fixed assets series are deflated separately using gross value added and gross fixed capital formation deflators from Eurostat National Account Statistics to ensure comparability over time. Second, firm-level information on real value added, real fixed assets and employment are used to construct measures of labour productivity and multifactor productivity (MFP). MFP is based on the Wooldridge (2009) methodology. Third, only enterprises with valid and relevant information are kept after filtering and cleaning.

### *2.2 Baseline model*

14. The empirical specification departs from an endogenous growth model of technology diffusion developed by Aghion and Howitt (1997) and Acemoglu *et al*. (2006). This empirical model has been applied in several OECD studies at the firm-level (e.g. Gal *et al*., 2019). Growth in labour productivity for non-frontier firms is assumed to follow the following process:

$$\Delta lnLP_{i,s,t} = \alpha_1 \Delta lnLP_{frontier,s,t} + \alpha_2 gap_{i,s,t-1} + \alpha_3 X_{i,s,t} + \alpha_4 Z_{i,s,t} + \eta_s + \tau_t + \varepsilon_{i,s,t} \quad (1)$$

$$\text{where } gap_{i,s,t-1} = lnLP_{frontier,s,t-1} - lnLP_{i,s,t-1}$$

15. $\Delta lnLP_{i,s,t}$ is the change in the logarithm of labour productivity of non-frontier firm $i$ in sector $s$ and in year $t$ measured by real value added divided by employees. The sample of non-frontier firms excludes the frontier firms, which are the 5 percent most productive firms in each sector ($s$) and year ($t$). Firm-level labour productivity is assumed to depend on labour productivity growth of frontier firms ($\Delta lnLP_{frontier,s,t}$), and on the lagged distance to the frontier firms ($gap_{i,s,t-1}$). The productivity frontier is expected to raise productivity growth in other firms with a factor below 1, so that the value of $\alpha_1$ is expected to be lower than 1 as innovation at the frontier benefits other firms, but only partially. Economic theory predicts catch-up of follower firms to the frontier, measured by a positive value of $\alpha_2$.

16. $X_{i,s,t}$ is a vector of variables measuring digital adoption, software investment and digital skill use at work. The coefficients of interest is $\alpha_3$, which captures the effect of digital adoption, software investment and digital skill use on firm-level productivity growth, respectively. Separate regressions are estimated for each digital technology, software investment and each digital skill. Interaction terms testing for synergies between digital adoption, software investment and skills are also included in separate regressions. For instance, as digital adoption may require software investment and skills, one might expect a positive interaction effect on productivity. $Z_{i,s,t}$ is a vector of firm-level control variables, including the logarithm of investment in physical capital per worker (excluding investment in software), firm age and size. As the model controls for physical capital, the coefficients can already be interpreted as effects on MFP. $\eta_s$ and $\tau_t$ are sector- and year-fixed effects that account for differences across sectors and annual time trends, respectively, and $\varepsilon_{i,s,t}$ is an independent and identically distributed random error term. Robustness tests include the use of MFP as dependent variable and the robust productivity frontier based on the 2-year moving average of firm-level labour productivity. The robust productivity frontier accounts for short-term

entry-and-exit frontier dynamics, but it excludes firms that are not covered in the sample in two consecutive years. The descriptive statistics are shown in (Table 2). Economic sectors are defined according to the NACE Revision 2 industry classification. In line with previous literature (Gal *et al.*, 2019; Andrews *et al.,* 2016), agriculture, forestry and fishing, financial and insurance activities, public administration, defence, education, human health and social work activities are excluded. Dummy indicators of firms belonging to manufacturing (NACE Rev. 2 10-33) or services sectors (NACE Rev. 2 45-82) are created and interacted with the technology adoption, software investment and skill use variables for additional analyses of differences in productivity effects across sectors. Likewise, a dummy variable for firm size is constructed for small firms (10 to 49 employees), medium-sized firms (50 to 249 employees), and large firms (250 or more employees) to test for differential productivity effects across firm sizes. Moreover, a dummy variable for firm age is constructed for young firms (established after 2009) and incumbent firms (established in 2009 or before) to test for productivity differences between young enterprises and incumbent firms. An additional analysis interacts firm age with digital and skill use variables. Finally, dummy variables that divide the sample according to lagged productivity quartiles in each industry, from lowest to highest initial productivity levels, are interacted with digital and skill use variables to test for differences in productivity effects across the firm productivity distribution.

## Table 2. Descriptive statistics

| | Mean | Median | Bottom decile | Top decile | Standard deviation | Observations |
|---|---|---|---|---|---|---|
| Unbalanced panel with 10 289 firms over 7 years (2012-2017) | | | | | | |
| **Dependent variable** | | | | | | |
| Labour productivity growth (log) | 0.00 | 0.01 | -0.30 | 0.30 | 0.41 | 10164 |
| Multifactor productivity growth (log) | 0.02 | 0.01 | -0.24 | 0.26 | 0.31 | 1556 |
| **Control variables** | | | | | | |
| Frontier growth (log) | 0.02 | 0.03 | -0.22 | 0.25 | 0.30 | 10849 |
| Gap to frontier (log) | 0.91 | 0.83 | 0.19 | 1.71 | 0.71 | 21451 |
| Capital per worker excl. ICT and software (log) | 5.26 | 5.43 | 1.60 | 8.44 | 2.61 | 12364 |
| Firm age in years (log) | 1.38 | 1.30 | 0.70 | 1.67 | 1.25 | 22641 |
| Firm size in employees (log) | 4.54 | 4.40 | 3.13 | 6.16 | 1.20 | 22638 |
| Sectoral ICT skill shortage | 0.16 | 0.12 | 0.03 | 0.35 | 0.14 | 19101 |
| **Digital and intangible variables** | | | | | | |
| **ICT infrastructure** | | | | | | |
| ICT hardware investment | 0.21 | 0.10 | 0.01 | 0.61 | 0.25 | 10959 |
| High-speed broadband dummy | 0.69 | 1.00 | 0.00 | 1.00 | 0.46 | 22594 |
| **Intangibles including skills** | | | | | | |
| Software investment | 0.23 | 0.11 | 0.01 | 0.69 | 0.27 | 11076 |
| ICT specialist skills | 0.05 | 0.01 | 0.00 | 0.08 | 0.16 | 18683 |
| Software specialist skills | 0.02 | 0.00 | 0.00 | 0.04 | 0.07 | 18683 |
| Computer use at work | 0.73 | 0.90 | 0.20 | 1.00 | 0.32 | 22646 |
| ICT training dummy | 0.46 | 0.00 | 0.00 | 1.00 | 0.50 | 15146 |
| **Digital technologies** | | | | | | |
| CRM/ERP dummy | 0.83 | 1.00 | 0.00 | 1.00 | 0.38 | 22648 |
| Cloud computing dummy | 0.50 | 0.00 | 0.00 | 1.00 | 0.50 | 11536 |
| Big data analytics dummy | 0.36 | 0.00 | 0.00 | 1.00 | 0.48 | 11796 |
| **Variables for additional analyses** | | | | | | |
| Services sector dummy | 0.66 | 1.00 | 0.00 | 1.00 | 0.47 | 22648 |
| Manufacturing sector dummy | 0.26 | 0.00 | 0.00 | 1.00 | 0.44 | 22648 |
| Small enterprise dummy | 0.33 | 0.00 | 0.00 | 1.00 | 0.47 | 22648 |
| Medium-sized enterprise dummy | 0.47 | 0.00 | 0.00 | 1.00 | 0.50 | 22648 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Large enterprise dummy | 0.20 | 0.00 | 0.00 | 1.00 | 0.40 | 22648 |
| Young enterprise dummy | 0.14 | 0.00 | 0.00 | 1.00 | 0.34 | 22648 |
| Incumbent enterprise dummy | 0.86 | 1.00 | 0.00 | 1.00 | 0.34 | 22648 |
| Digital-intensive sector dummy | 0.37 | 0.00 | 0.00 | 1.00 | 0.48 | 22660 |

Note: Multifactor productivity (MFP) is based on the Wooldridge (2009) methodology.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

### *2.3 Identification strategy*

17. Endogeneity complicates the econometric identification of productivity effects. Endogeneity issues can result from both reverse causality and unobserved common confounding factors influencing productivity and digitalisation. Reverse causality arises when more productive firms are more likely to adopt digital technologies and invest in intangibles, either due to economies of scale or stronger financial means. In addition, common confounding factors might drive productivity and digital adoption. For instance, firms with a better management may be more likely to use new technologies (Andrews *et al*., 2018) and may be more productive for this reason (Bloom, *et. al*, 2012). If not properly addressed, endogeneity leads to biased estimates.

18. In order to address these concerns, this paper follows the empirical literature on causal effects of digitalisation (e.g. Acemoglu and Restrepo, 2020; Cette *et al*., 2020) and applies an instrumental variable (IV) approach (two-stage least squares, 2SLS). It uses firm $i$'s exposure to sector-wide advances in technology and intangible intensity as an exogenous instrument for firm-level measures of digital and intangible variables ($X_{i,s,t}$). More specifically, the exposure variable is derived from lagged firm-level adoption and intangible intensity and sector-wide means of digital adoption and intangible intensity. The exposure variable measures the deviation of lagged firm-level digital and intangible measures from their sector-wide mean. Firms that utilise digital technologies more (less) effectively to increase productivity than the sector average will have stronger (weaker) incentives to increase their uptake of a concrete digital technology. They are therefore expected to be more (less) exposed to sector-wide technology advances that lower adoption costs, for example due to sector-wide learning. Any impacts on productivity arise only through the exposure to sector-wide spillover effects, resting on the crucial assumption that these technology benefits are exogenous to the firm and affect firm $i$'s productivity only via the sector-wide spillovers. In other words, all firms are small relative to the overall sector, and an individual firm's decisions are unlikely to affect sector-wide measures of technology and skill use. There may be concerns that a single firm drives sector-wide digital and intangible intensities as digital-intensive industries tend to become more concentrated. In order to account for industry concentration, sector-wide leave-one-out means are used that exclude firm $i$'s own contribution to sector-wide digital adoption and intangible intensity. The approach addresses omitted variable bias and reverse causality simultaneously.

19. In a first stage, the exposure measure $\hat{X}_{i,s,t}$ is derived from regressing firm-level digital and intangible variables on sector-level means of these variables and lagged firm-level digital and intangible variables as shown in equations (2) and (3):

$$X_{i,s,t} = a_1 \Delta lnLP_{frontier,s,t} + a_2 gap_{i,s,t-1} + \delta X_{i,s,t-1} \times \bar{X}_{s,t} + a_3 Z_{i,s,t} + \eta_s + \tau_t + u_{i.s.t} \quad (2)$$

$$\hat{X}_{i,s,t} = \hat{a}_1 \Delta lnLP_{frontier,s,t} + \hat{a}_2 gap_{i,s,t-1} + \hat{\delta} X_{i,s,t-1} \times \bar{X}_{s,t} + \hat{a}_3 Z_{i,s,t} + \hat{\eta}_s + \hat{\tau}_t \quad (3)$$

where $X_{i,s,t}$ is the firm-level measure of the adoption of a concrete digital technology, software investment or digital skill use of firm $i$ operating in sector $s$ at time $t$. It is regressed on the sectoral (sample) mean of the measure of the adoption of a concrete digital technology, software investment or digital skill use of sector $s$ at time $t$ ($\bar{X}_{s,t}$) interacted with lagged firm-level measures of the adoption of a concrete digital technology, software investment or digital skill use of firm $i$, respectively. The predicted values from these regressions $\hat{X}_{i,s,t}$ are the exposure measures and predict whether firm $i$ has an advantage (disadvantage) over the sector in terms of higher (lower) digital adoption, software investment or digital skill use, respectively. Replacing the vector of digital and skill use variables $X_{i,s,t}$ in (1) by the IV $\hat{X}_{i,s,t}$ from (3) yields the second stage estimation model for non-frontier firms:

$$\Delta lnLP_{i,s,t} = a_1 \Delta lnLP_{frontier,s,t} + a_2 gap_{i,s,t-1} + a_3 \hat{X}_{i,s,t} + a_4 Z_{i,s,t} + \eta_s + \tau_t + v_{i,s,t} \quad (4)$$

20. The identification rests on the assumption that firms in sectors with higher digital adoption, software investment, or digital skill use at work are not affected by other productivity shocks or trends that simultaneously affect digitalisation and productivity. For instance, industries exposed to skill shortages could respond with both higher digital adoption and productivity. Sector and year fixed effects and additional control variables control for such shocks and trends. Standard errors are clustered by sector to account for potential issues arising from the sample design of the business survey (Abadie *et al.*, 2017). For example, some sectors might be overrepresented. Additional results show that the exposure variable is not affected by sector-wide developments that are correlated both with the digital and intangible variables and average productivity growth in the sector (Table B.2 in Annex B). Therefore, the IV should only capture the extent to which a firm's productivity is affected by sector-wide advances in digital and skill measures.

## 3. Results

### *3.1 OLS specification*

21. (Table 3) presents the results for labour productivity growth from the ordinary least squares (OLS) specification in equation (1) for the full sample. The economic significance is discussed in a separate paragraph below. Various variables capturing digital adoption and intangibles are positively and statistically significantly associated with productivity growth. The findings reveal that investment in ICT hardware and high-speed broadband are positively and statistically significantly associated with productivity growth. Although ICT hardware investment is not a digital technology or an intangible asset, it is needed to put newest digital technologies and intangibles such as software into use. The employment of digital skills, a measure of intangible capital, is positively and statistically significantly associated with productivity growth across different measures of digital skill intensity. The exception are software specialist skills, where a sizeable positive coefficient is statistically insignificant potentially due to only 2% of employees in the sample having such skills. ICT specialist skills have the strongest association with productivity growth. Computer use at work and ICT training are also statistically significant. Other digital technologies are not statistically significant.

## Table 3. OLS regression results

| VARIABLES | ICT infrastructure | | Intangibles including skills | | | | | Digital technologies | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware invest. | Broad band (>30Mbit/s) | Software invest. | ICT specialist skills | Software specialist skills | Computer use at work | ICT training | CRM/ ERP | Cloud computing | Big data |
| Frontier growth | 0.162*** | 0.165*** | 0.166*** | 0.158*** | 0.158*** | 0.169*** | 0.160*** | 0.167*** | 0.173*** | 0.168*** |
| | (0.024) | (0.021) | (0.021) | (0.029) | (0.029) | (0.022) | (0.029) | (0.022) | (0.040) | (0.025) |
| Gap to the frontier (lagged) | 0.251*** | 0.245*** | 0.248*** | 0.251*** | 0.251*** | 0.252*** | 0.254*** | 0.248*** | 0.264*** | 0.248*** |
| | (0.024) | (0.021) | (0.023) | (0.027) | (0.027) | (0.023) | (0.028) | (0.022) | (0.035) | (0.027) |
| Capital per worker | 0.024*** | 0.014*** | 0.017*** | 0.015*** | 0.015*** | 0.015*** | 0.014*** | 0.015*** | 0.017*** | 0.016*** |
| | (0.005) | (0.004) | (0.004) | (0.004) | (0.004) | (0.003) | (0.004) | (0.004) | (0.004) | (0.004) |
| Firm age | 0.001 | -0.002 | -0.001 | 0.000 | 0.000 | -0.001 | -0.004 | -0.001 | -0.003 | 0.008 |
| | (0.005) | (0.005) | (0.005) | (0.005) | (0.005) | (0.005) | (0.006) | (0.005) | (0.007) | (0.006) |
| Firm size (medium-sized enterprise) | -0.028** | -0.037*** | -0.031** | -0.032** | -0.032** | -0.030** | -0.040*** | -0.030** | -0.032* | -0.029 |
| | (0.013) | (0.013) | (0.013) | (0.013) | (0.013) | (0.014) | (0.013) | (0.014) | (0.017) | (0.019) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Firm size (large enterprise) | -0.010 | -0.025 | -0.012 | -0.021 | -0.021 | -0.015 | -0.039** | -0.015 | -0.029 | -0.015 |
| | (0.016) | (0.017) | (0.017) | (0.018) | (0.018) | (0.018) | (0.017) | (0.018) | (0.024) | (0.026) |
| Digital and intangible variable | 0.129*** | 0.033*** | 0.038 | 0.084** | 0.049 | 0.065** | 0.033** | -0.003 | 0.007 | 0.005 |
| | (0.030) | (0.008) | (0.028) | (0.035) | (0.086) | (0.029) | (0.014) | (0.015) | (0.009) | (0.013) |
| Constant | -0.301*** | -0.284*** | -0.297*** | -0.271*** | -0.268*** | -0.317*** | -0.273*** | -0.275*** | -0.271*** | -0.302*** |
| | (0.033) | (0.029) | (0.031) | (0.038) | (0.038) | (0.042) | (0.040) | (0.032) | (0.052) | (0.042) |
| Time fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Sector fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 5,004 | 5,521 | 4,976 | 4,300 | 4,300 | 5,530 | 4,300 | 5,531 | 3,324 | 3,754 |
| R-squared | 0.151 | 0.147 | 0.144 | 0.149 | 0.148 | 0.149 | 0.150 | 0.147 | 0.170 | 0.144 |

Note: The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Digital and intangible variable denotes variables shown in the first row: ICT hardware investment, broadband (>30Mbit/s), software investment, ICT specialist skills, software specialist skills, computer use at work, ICT training, CRM and ERP front-office software, cloud computing, and big data analytics. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Main results highlighted.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

22. The main control variables have the expected sign and are for the most part significant. A 1% increase in frontier growth is associated with labour productivity growth by a factor below one, in line with economic theory. It points to a positive role of technology transfer for productivity growth of non-frontier firms. The lagged productivity gap to the frontier is associated with higher productivity growth, implying that follower firms are catching-up with the frontier conditional on survival. Interestingly, the size of the coefficient for the lagged productivity gap is higher than the size of the coefficient for frontier growth in all models. This finding is consistent with recent OECD evidence on laggard firms and technology diffusion (Berlingieri *et al.*, 2020) and suggests a strong productivity catch-up of laggards in the Netherlands. As expected, investments in physical capital are positively associated with labour productivity growth, showing that as firms become more capital intensive they also have higher labour productivity. Firm age is not significant, while there is a negative association with firm size: medium-sized and large firms have lower productivity growth than small firms, although the effect for larger firms is not statistically significant.

## *3.2 Baseline specification*

### *Digital adoption and intangibles lead to higher productivity growth*

23. Table 4 presents results from the baseline specification (the 2SLS empirical specification) in equation (4). The economic significance is discussed below. The results mirror the OLS regression results and confirm that ICT hardware investment and fast broadband connections are highly statistically significant. Results also show that ICT specialist skills and software specialist skills have a positive and statistically significant effect on productivity growth, albeit only at the 10% level of statistical significance for software specialists. The size of the coefficients is higher in the IV estimation than in the OLS estimation, which suggests considerable firm benefits arising from the sector-wide availability of ICT and software specialists. By contrast, computer use at work and ICT training are statistically significant. Other digital technologies are not statistically significant. A joint estimation of digital and intangible measures confirms the results (Table C.1 in Annex C).

## Table 4. Baseline results

| VARIABLES | ICT infrastructure | | Intangibles including skills | | | | | Digital technologies | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware invest. | Broadband (>30Mbit/s) | Software invest. | ICT specialist skills | Software specialist skills | Computer use at work | ICT training | CRM/ ERP | Cloud computing | Big data |
| Frontier growth | 0.162*** | 0.164*** | 0.167*** | 0.174*** | 0.175*** | 0.167*** | 0.140*** | 0.167*** | 0.102 | 0.190*** |
| | (0.023) | (0.021) | (0.023) | (0.030) | (0.030) | (0.022) | (0.028) | (0.022) | (0.062) | (0.038) |
| Gap to the frontier (lagged) | 0.272*** | 0.244*** | 0.270*** | 0.299*** | 0.299*** | 0.248*** | 0.286*** | 0.248*** | 0.211*** | 0.214*** |
| | (0.019) | (0.021) | (0.019) | (0.026) | (0.026) | (0.022) | (0.027) | (0.022) | (0.038) | (0.031) |
| Capital per worker | 0.018*** | 0.015*** | 0.016*** | 0.016*** | 0.016*** | 0.015*** | 0.016*** | 0.015*** | 0.008 | 0.013*** |
| | (0.004) | (0.004) | (0.004) | (0.005) | (0.005) | (0.004) | (0.005) | (0.004) | (0.005) | (0.004) |
| Firm age | -0.005 | -0.002 | -0.005 | -0.013* | -0.013* | -0.001 | -0.007 | -0.001 | 0.005 | 0.012 |
| | (0.006) | (0.005) | (0.005) | (0.007) | (0.007) | (0.005) | (0.009) | (0.005) | (0.008) | (0.008) |
| Firm size (medium-sized enterprise) | -0.032* | -0.033** | -0.032** | -0.030 | -0.029 | -0.031** | -0.026 | -0.031** | -0.036* | -0.033* |
| | (0.018) | (0.013) | (0.016) | (0.019) | (0.019) | (0.014) | (0.025) | (0.014) | (0.019) | (0.018) |
| Firm size (large enterprise) | -0.016 | -0.018 | -0.019 | -0.013 | -0.012 | -0.016 | -0.001 | -0.016 | -0.037 | -0.021 |
| | (0.022) | (0.017) | (0.018) | (0.022) | (0.022) | (0.018) | (0.028) | (0.018) | (0.027) | (0.023) |
| Digital and intangible variable | 0.154*** | 0.028*** | 0.024 | 0.156*** | 0.289* | 0.009 | 0.012 | 0.002 | 0.007 | 0.013 |
| | (0.041) | (0.010) | (0.034) | (0.033) | (0.146) | (0.031) | (0.019) | (0.017) | (0.018) | (0.014) |
| Constant | -0.294*** | -0.269*** | -0.275*** | -0.303*** | -0.303*** | -0.277*** | -0.309*** | -0.278*** | -0.179*** | -0.298*** |
| | (0.034) | (0.028) | (0.031) | (0.038) | (0.038) | (0.031) | (0.037) | (0.031) | (0.054) | (0.047) |
| Time fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Sector fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 3,367 | 5,516 | 3,418 | 2,868 | 2,868 | 5,527 | 2,067 | 5,531 | 1,689 | 2,663 |
| R-squared | 0.173 | 0.146 | 0.163 | 0.187 | 0.186 | 0.147 | 0.156 | 0.147 | 0.141 | 0.137 |

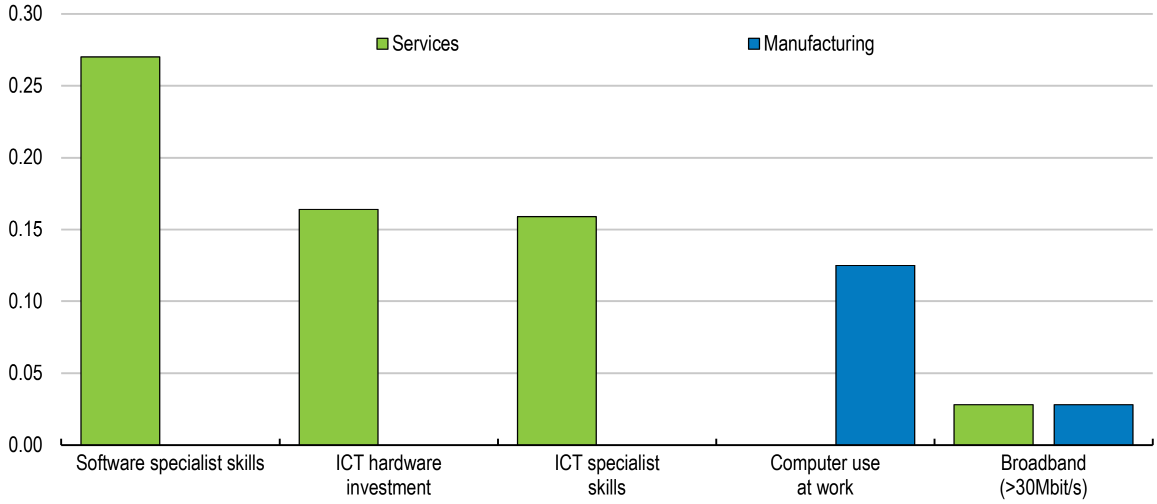
Note: The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Digital and intangible variable denotes variables shown in the first row: ICT hardware investment, broadband (>30Mbit/s), software investment, ICT specialist skills, software specialist skills, computer use at work, ICT training, CRM and ERP front-office software, cloud computing, and big data analytics. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Main results highlighted.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

### *Firms in the service sectors benefit most from intangibles*

24. The following results look at manufacturing and service sectors separately. The effect of ICT hardware investment varies between manufacturing and services, with a larger coefficient in services (Figure 1 and Table C.2 in Annex C). Among service sector firms, the coefficient for ICT hardware investment is statistically significant, while it is not for manufacturing. Increasing investment in ICT hardware as a share of total assets by one standard deviation translates into a direct gain of an additional 17.3% productivity growth for service sector firms. A similar picture emerges for ICT specialist skills and software specialist skills, which are statistically significant for services but not for manufacturing. Broadband internet has a sizeable and statistically significant effect on labour productivity growth for all firms, irrespective of their sector, although for service firms only at the 10% level of statistical significance.

### Figure 1. Annual effect on firm-level labour productivity growth for services versus manufacturing

Only statistically significant results at the 10% significance level are shown



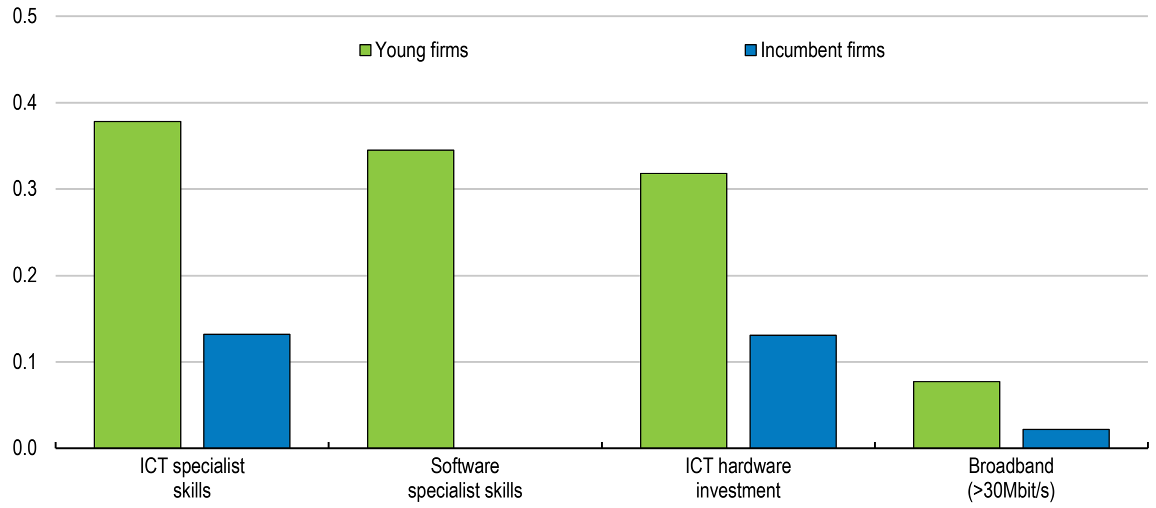

Note: Table C.2 in Annex C shows the full results. The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Results are based on estimates of the IV regression presented in Eq. 4 of this paper. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

#### *Young firms also benefit from intangibles*

25. Results further suggest that younger firms, established after the financial crisis, derive greater productivity benefits from intangibles than incumbent firms (or firms established before the financial crisis). ICT hardware investment is positive and statistically significant among young firms, and the coefficient estimate is larger than for incumbent firms (Figure 2 and Table C.3 in Annex C). Younger firms also appear to draw stronger productivity effects of ICT specialist skills and software specialist skills. Similarly, the coefficient estimate for broadband internet access is statistically significant and larger for young firms. The finding implies that younger firms established after the financial crisis may follow a different growth strategy that is based on intangible capital, which can be scaled-up faster and at lower costs than physical capital. Additional analysis that tests for the effect of firm age confirms that older firms derive greater productivity benefits from fast broadband connections and ICT hardware investment, but not from measures of intangible intensity (Table C.4 in Annex C).

## Figure 2. Annual effect on firm-level labour productivity growth for young versus incumbent firms

Only statistically significant results at the 10% significance level are shown




Note: Table C.3 in Annex C shows the full results. The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Results are based on estimates of the IV regression presented in Eq. 4 of this paper. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

### *Digital adoption supports productivity catch-up of laggard enterprises*

26. Table 5 shows the results for productivity growth effects across the firm productivity distribution. Results are based on estimates of the baseline regression presented in equation 4 of this paper. In addition, it uses dummy variables that divide the sample by lagged productivity quartiles in each industry, from lowest to highest initial productivity levels, excluding the 5% most productive firms for endogeneity concerns. In order to get the total effect across productivity quartiles, the coefficient of digital and skill use variables and the coefficient of the interaction term of digital and skill use variables and lagged productivity quartile dummy are added up.

27. The findings show that firm-level productivity benefits from ICT hardware investment are strongest for firms that were highly productive at the outset. It suggests that for productivity effects of ICT hardware to arise, firms may need to have in place other productivity-enhancing capital, skills and/or good management. On the contrary, productivity effects of software investment are also strong for low productivity firms. This may suggest that low-productivity firms derive greater productivity benefits from software where initial fixed costs are lower and scaling-up opportunities are higher. It implies that software investment has the potential to support the productivity catch up of laggard firms, but low software adoption among laggards still hampers broader productivity gains. Differences across low and high productivity firms for digital skills and other digital technologies are not statistically significant.

## Table 5. Effects across productivity quartiles

| VARIABLES | **ICT infrastructure** | | **Intangibles including skills** | | | | **Digital technologies** | | |
|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware investment | Broadband (>30Mbit/s) | Software investment | ICT specialist skills | Software specialist skills | Computer use at work | CRM/ ERP | Cloud computing | Big data |
| Quartile 1 (lowest) | 0.149** | 0.043 | 0.072*** | 0.067 | 0.201 | 0.044 | -0.043 | 0.039 | 0.030 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Quartile 2 | 0.144** | 0.035 | -0.033** | 0.138 | 0.410 | 0.001 | 0.010 | -0.005 | -0.016 |
| Quartile 3 | 0.202** | 0.045 | 0.017** | 0.176 | 0.419 | -0.068 | 0.047 | -0.032 | 0.014 |
| Quartile 4 (highest) | 0.094** | -0.014 | 0.027** | 0.173 | 0.165 | 0.025 | 0.015 | 0.039 | 0.022 |

Note: The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Results are based on estimates of IV regression presented in Eq. 4 of this paper, adding dummy variables that divide the sample by lagged productivity quartiles in each industry. In addition, interaction terms of digital and intangible variables with lagged productivity quartile dummies are included. Results for effects across productivity quartiles show the combined effect of digital/intangible variables and the interaction of digital/intangible variables and productivity quartile dummies. Digital and intangible variable denotes variables shown in the first row: ICT hardware investment, broadband (>30Mbit/s), software investment, ICT specialist skills, software specialist skills, computer use at work, CRM and ERP front-office software, cloud computing, and big data analytics. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

### *Economic significance*

28. After establishing the econometric significance of hardware investment, digital skills and digital adoption, the greater interest lies in the economic significance for firms and the entire economy. To illustrate this, the regression coefficients from the baseline specification in (Table 4) are re-scaled to make them comparable. The results should be interpreted as a lower bound of the total macro-economic effect as the analysis relies only on within-firm productivity growth. Digital technologies and intangible investment could contribute to higher aggregate productivity through better allocation of resources across firms. For instance, high productive firms that make the necessary investment in intangibles may be able to hire more workers, which would contribute to overall labour productivity. It should be noted that the estimates represent only the lower bound of productivity effects if the fixed effects do not capture smaller average effects on within-firm productivity growth.

29. Results in (Table 6) show the productivity effects measured in annual percent point change if all firms (first row) and all sectors (second row) would increase selected measures of digital adoption and intangible investment by one standard deviation. Increasing ICT hardware investment as a share of total fixed assets by one standard deviation will lead to a 1.5% increase in annual productivity growth for the average Dutch enterprise (first column). Increases in digital skill use intensity are considerable and range from 10.3% for software specialist skills to 1.3% for ICT specialist skills. Productivity gains for Dutch enterprises also arise from the uptake of high-speed broadband. Turning to economy-wide effects, the highest productivity effect comes from digital skill use at work. Productivity growth premiums range from 6.5% for software specialist skills to 0.8% ICT specialist skills. Economy-wide effects are also substantial for ICT hardware investment.

## Table 6. Illustration of productivity effects from digital adoption and intangible investment

| VARIABLES | ICT hardware investment | Broadband (>30Mbit/s) | ICT specialist skills | Software specialist skills |
|---|---|---|---|---|
| Firm effect | 0.015 | 0.028 | 0.013 | 0.103 |
| Economy- wide effect | 0.010 | 0.001 | 0.008 | 0.065 |

Note: Firm effects - for measures of investment and skill use intensity, the adopting firm is assumed to increase investment intensity/skill use with one standard deviation based on estimates of IV regressions presented in Table 4 of this paper. Insignificant coefficients are not included. For broadband, which is a binary variable, firms are either adopters or non-adopters. Sector effects are calculated for a one standard deviation increase and scaled by the share in total value added of the sectors included in this analysis (approximately 63%) to arrive at an estimate of the average effect for the total economy.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

### *Caveats and consistency checks*

30. The results of the IV estimation are robust to using (i) an exposure variable based on initial firm-level digital and intangible intensity from 2012 (Table C.5 in Annex C), (ii) MFP as dependent variable (Table C.6 in Annex C), (iii) a robust productivity frontier based on the 2-year moving average of firm-level labour productivity (Table C.7 in Annex C), and (iv) the including of sector-year fixed effects to not control for time varying shocks that differ across sectors (Table C.8 in Annex C).

31. A potential source of concern is that digital adoption rates and skill use intensities may capture the effects of other omitted variables that may affect productivity, digital adoption and skill use. For instance, skill shortages dampen productivity growth by making it harder for productive firms to attract skilled workers (Adalet McGowan and Andrews, 2015) and by holding back digital adoption. To control for this possibility, sector-level ICT skill shortages are included as additional variables. As shown in Table C.9 (in Annex C), results are robust to the inclusion of sectoral skill shortages.

32. Another concern is that larger firms may be in a better financial position to conduct the necessary investment in digital technologies and intangible capital. In general, productivity effects from digital adoption and intangibles do not seem to depend on firm size in the Netherlands (Table C.10 in Annex C). The exception are productivity benefits from ICT and software specialist skills, which are higher for larger firms. While larger firms tend to have higher adoption rates of digital technologies, there are no significant differences in productivity gains once a firm adopts digital technologies. This is in line with previous firm-level evidence (Mosiashvili and Pareliussen, 2020), and suggests that smaller productive firms are not discouraged by initial fixed costs associated with digital adoption and software investment.

33. As digital adoption and software require skills, one might expect a positive interaction effect between digital skill use at work and digital adoption/intangible intensity on productivity, reflecting the complementary nature of these variables in a firm's production process. Unreported results do not confirm such complementarities. This may related to the measure used for digital skills, which is based on formal employed in an ICT related job, leaving aside other important intangibles such as organisational capital, management skills and research and development.

34. This study analysed whether productivity effects from digital adoption and intangibles differ across the manufacturing and the service sector. A related question is whether productivity effects from digital adoption and intangibles may differ across industries within these sectors as industries differ in their digital maturity (Calvino *et al.*, 2018). Unreported results do not confirm such differences between digital-intensive sectors and less digital-intensive sectors for the Netherlands. This suggests that there are mainly differences between firms within industries, rather than between firms in different industries, which confirms the importance of firm-level data to analyse these issues.

35. Several limitations remain. First, the IV approach reduces most endogeneity concerns but not all of them. Only endogeneity of digital adoption and intangibles is taken into account, while endogeneity may still affect other measures such as capital intensity. For example, productivity and capital intensity may be affected by unobserved factors such as management skills. Endogeneity issues can also arise if one firm drives sector-wide advancement in digital adoption or skill use. Using data on sector-wide digital adoption, software and skill use intensity from outside of the Netherlands could address this concern. Furthermore, the measure of digital skills is rather limited as it is based on employment of dedicated ICT/software specialists. The employment of such specialists does not say anything about the availability of ICT skills more broadly in the firm, including manager skills. The paper also leaves aside potential impacts from trade and geographical spillovers, which may contribute to digital adoption and productivity growth. Further, the paper does not take into account possible productivity effects of reallocation from less productive firms to more productive firms. And lastly, given its focus on the Netherlands, it cannot compare the effect of productivity policies such as e.g. regulatory environment and flexible labour markets directly, as they are set at the national level and do not provide sufficient variation over time for the estimation.

## 4. Summary and conclusions

36. This paper provides robust evidence on firm-level productivity effects of digital adoption and intangible investment in the Netherlands. Results show that intangibles as measured by levels of digital skill intensity have a positive impact on firm-level productivity, highlighting the productivity potential of intangibles for the Dutch economy. All things equal, an increase in the employment shares of software specialists and ICT specialists by a standard deviation can improve a firm's labour productivity by about 10.3% and 1.3% a year, respectively. These findings point to the importance of policies supporting adequate digital skill supply to reap productivity benefits, including policies supporting the re-skilling and up-skilling of workers. Furthermore, productivity benefits from software investment are strong for low productivity firms, pointing to the potential of intangibles to support the productivity catch-up of laggards, and suggest that increasing software uptake among laggard enterprises can help moving their productivity performance closer to the frontier.

37. Second, the findings suggest that Dutch firms have incentives to invest in digital technologies and intangibles, but differences across sectors exist. The effect of ICT hardware investment, ICT specialist skills and software specialist skills varies significantly between manufacturing and services, with a larger effect in services. It is in line with similar results presented for Estonia, where firm-level productivity effects from digital technology were found to be overall stronger in services than manufacturing (Mosiashvili and Pareliussen, 2020). By contrast, there is room to increase intangible investment among manufacturing firms to support productivity.

38. Third, younger firms derive greater productivity benefits from intangibles than incumbent firms. It confirms a pattern specific to the Netherlands, where good market dynamics helped by lean business regulations enables young productive firms to catch up to the productivity frontier on the back of stronger intangible investment (Van Heuvelen *et al*., 2018).

39. Finally, and in line with prior evidence (Mosiashvili and Pareliussen, 2020; Gal *et al.*, 2019; Sorbe *et al.*, 2019), the productivity gain from fast internet access is sizeable for the average Dutch firm. Productivity effects from ICT hardware investment are also positive and significant. It implies an untapped catch-up potential that could be harnessed by further moving high-speed broadband uptake and ICT hardware intensity in laggard firms closer to those of frontier.

40. The COVID-19 shock and associated mobility restrictions seem to have further boosted the use of digital technologies by firms. Future research could analyse how the accelerated pace of digitalisation affects productivity growth. Furthermore, building on recent OECD work (Gal *et al.*, 2019; Sorbe *et al.*, 2019), research could extend the country coverage and analyse the role of policies to strengthen the impact of digitalisation on productivity.

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# Annex A. Correlation between digital adoption and intangible intensity

### Table A.1. The correlation between digital adoption and intangible intensity measures

| VARIABLES | ICT infrastructure | | Intangibles including skills | | | | | Digital technologies | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware invest. | Broad-band (>30 Mbit/s) | Software invest. | ICT specialist skills | Software specialist skills | Computer use at work | ICT training | CRM/ ERP | Cloud computing | Big data |
| ICT hardware invest. | 1.000 | | | | | | | | | |
| Broad-band (>30 Mbit/s) | 0.017 | 1.000 | | | | | | | | |
| Software invest. | 0.243 | 0.011 | 1.000 | | | | | | | |
| ICT specialist skills | 0.181 | 0.090 | 0.136 | 1.000 | | | | | | |
| Software specialist skills | 0.109 | 0.084 | 0.125 | 0.572 | 1.000 | | | | | |
| Computer use at work | 0.198 | 0.183 | 0.150 | 0.222 | 0.202 | 1.000 | | | | |
| ICT training | 0.020 | 0.220 | -0.009 | 0.243 | 0.218 | 0.226 | 1.000 | | | |
| CRM/ ERP | -0.039 | 0.121 | 0.023 | 0.033 | 0.060 | 0.092 | 0.187 | 1.000 | | |
| Cloud computing | 0.043 | 0.170 | 0.054 | 0.119 | 0.107 | 0.184 | 0.236 | 0.135 | 1.000 | |
| Big data | -0.019 | 0.113 | 0.001 | 0.076 | 0.107 | 0.105 | 0.245 | 0.144 | 0.203 | 1.000 |

Source: Authors' calculations based on business survey data from Statistics Netherlands.

# Annex B. Validity of the instrumental variable

41. The instrumental variables appears to be valid: They have a high correlation with firm-level digital adoption, software investment and digital skill use at work (Table B.1). The F-statistics on the excluded instruments in the first stage is in all cases greater than 10 with the exception of ICT hardware investment, which suggests that the instruments are not weak. Furthermore, the exposure variable is not affected by sector-wide developments that are correlated both with the digital and intangible variables and average productivity growth in the sector: Results confirm that the correlation between the labour productivity growth and the instrumental variables at the sector level is statistically insignificant, as are most correlations between instrumental variable and skill shortages at the sector-level (Table B.2). The exceptions are ICT hardware investment, ICT specialist skills, software programmer skills and ICT training, albeit the correlation is only significant at the 10% significance level. In order to test whether the effects of skill shortages differ from the effects of digital adoption and intangible intensity, additional robustness checks were run verifying that controlling for skill shortages does not change our main estimate (Table C.9). It suggests that the instrumental variables are exogenous, i.e. uncorrelated with the error term, and correlated with the dependent variable only via the digital adoption, intangible intensity and digital skill use.

### Table B.1. IV estimation results, first and second stage

| VARIABLES | **ICT infrastructure** | | **Intangibles including skills** | | | | | **Digital technologies** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware invest. | Broad-band (>30 Mbit/s) | Software invest. | ICT specialist skills | Software specialist skills | Computer use at work | ICT training | CRM/ ERP | Cloud computing | Big data |
| Second stage coefficients | 0.154*** | 0.028*** | 0.024 | 0.156*** | 0.289* | 0.009 | 0.012 | 0.002 | 0.007 | 0.013 |
| | (0.041) | (0.010) | (0.034) | (0.033) | (0.146) | (0.031) | (0.019) | (0.017) | (0.018) | (0.014) |
| First stage coefficients | 0.347** | 0.593*** | 1.022*** | 1.794*** | 11.178*** | 0.875*** | 1.002*** | 0.230*** | 0.562*** | 0.842*** |
| | (0.131) | (0.033) | (0.211) | (0.254) | (1.271) | (0.063) | (0.102) | (0.029) | (0.051) | (0.073) |
| Time fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Sector fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 3367 | 5516 | 3418 | 2868 | 2868 | 5527 | 2067 | 5531 | 1689 | 2663 |
| R-squared | 0.173 | 0.146 | 0.163 | 0.187 | 0.186 | 0.147 | 0.156 | 0.147 | 0.141 | 0.137 |
| First stage F-statistic | 7.000 | 327.870 | 23.520 | 49.690 | 77.290 | 191.240 | 96.230 | 62.920 | 121.220 | 134.290 |

Note: In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity, based on sector-wide means of digital and intangible variables and the lagged firm-level digital and intangible variables. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

## Table B.2. IV validity tests

| VARIABLES | ICT infrastructure | | Intangibles including skills | | | | | Digital technologies | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware invest. | Broad-band (>30 Mbit/s) | Software invest. | ICT specialist skills | Software specialist skills | Computer use at work | ICT training | CRM/ ERP | Cloud computing | Big data |
| Sector-wide labour productivity growth | 0.014 | -0.002 | -0.000 | 0.002 | -0.006 | 0.033* | 0.005 | -0.002 | 0.035 | 0.011 |
| | (0.414) | (0.880) | (0.992) | (0.887) | (0.649) | (0.001) | (0.747) | (0.839) | (0.061) | (0.453) |
| Observations | 3592 | 10052 | 3646 | 5550 | 5550 | 10075 | 3903 | 10079 | 2886 | 4529 |
| Sector-wide skill shortages | -0.045* | 0.217 | 0.051 | -0.364* | 0.212* | 0.007 | 0.045* | -0.012 | 0.015 | 0.049 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.339) | (0.000) | (0.085) | (0.090) | (0.000) |
| Observations | 3833 | 10720 | 3884 | 5951 | 5951 | 10744 | 4149 | 10752 | 3703 | 4794 |

Note: *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

# Annex C. Additional regression results and robustness tests

## Table C.1. Joint estimation of digital and intangible measures

| VARIABLES | Labour productivity growth |
|---|---|
| Frontier growth | 0.144*** |
| | (0.037) |
| Gap to the frontier (lagged) | 0.326*** |
| | (0.037) |
| Capital per worker | 0.020*** |
| | (0.007) |
| Firm age | -0.022* |
| | (0.012) |
| Firm size (medium-sized enterprise) | -0.041 |
| | (0.030) |
| Firm size (large enterprise) | -0.013 |
| | (0.035) |
| ICT hardware investment | 0.373** |
| | (0.153) |
| Broadband (>30Mbit/s) | 0.049* |
| | (0.025) |
| Software investment | 0.209* |
| | (0.123) |
| ICT specialist skills | 0.161*** |
| | (0.057) |
| ICT training | 0.024 |
| | (0.033) |
| Constant | -0.305*** |
| | (0.052) |
| Time fixed effects | Yes |
| Sector fixed effects | Yes |
| Observations | 1,071 |
| R-squared | 0.236 |

Note: The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Digital and intangible variable denotes variables shown in the first row: ICT hardware investment, broadband (>30Mbit/s), software investment, ICT specialist skills, software specialist skills, computer use at work, ICT training, CRM and ERP front-office software, cloud computing, and big data analytics. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Main results highlighted.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

## Table C.2. Manufacturing versus services

| VARIABLES | ICT infrastructure | | Intangibles including skills | | | | Digital technologies | | |
|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware investment | Broadband (>30Mbit/s) | Software investment | ICT specialist skills | Software specialist skills | Computer use at work | CRM/ ERP | Cloud computing | Big data |
| Frontier growth | 0.163*** | 0.164*** | 0.167*** | 0.174*** | 0.175*** | 0.167*** | 0.167*** | 0.103 | 0.190*** |
| | (0.023) | (0.021) | (0.023) | (0.030) | (0.030) | (0.022) | (0.022) | (0.062) | (0.038) |
| Gap to the frontier (lagged) | 0.272*** | 0.244*** | 0.270*** | 0.300*** | 0.299*** | 0.249*** | 0.248*** | 0.211*** | 0.214*** |
| | (0.019) | (0.021) | (0.019) | (0.026) | (0.026) | (0.022) | (0.022) | (0.038) | (0.031) |
| Capital per worker | 0.018*** | 0.015*** | 0.016*** | 0.016*** | 0.016*** | 0.015*** | 0.015*** | 0.008 | 0.013*** |
| | (0.004) | (0.004) | (0.004) | (0.005) | (0.005) | (0.004) | (0.004) | (0.005) | (0.004) |
| Firm age | -0.005 | -0.002 | -0.005 | -0.013* | -0.013* | -0.001 | -0.001 | 0.005 | 0.012 |
| | (0.006) | (0.005) | (0.005) | (0.007) | (0.007) | (0.005) | (0.005) | (0.008) | (0.008) |
| Firm size (medium-sized enterprise) | -0.032* | -0.033** | -0.032** | -0.030 | -0.030 | -0.031** | -0.031** | -0.036* | -0.033* |
| | (0.018) | (0.013) | (0.016) | (0.019) | (0.019) | (0.014) | (0.014) | (0.019) | (0.018) |
| Firm size (large enterprise) | -0.017 | -0.018 | -0.019 | -0.013 | -0.014 | -0.017 | -0.016 | -0.038 | -0.021 |
| | (0.022) | (0.017) | (0.018) | (0.022) | (0.021) | (0.017) | (0.018) | (0.026) | (0.023) |
| Manufacturing | 0.054*** | -0.040*** | 0.077*** | 0.004 | 0.005 | -0.043*** | -0.045*** | 0.005 | -0.082*** |
| | (0.014) | (0.014) | (0.013) | (0.028) | (0.029) | (0.015) | (0.015) | (0.021) | (0.021) |
| Digital and intangible variable (services) | 0.164*** | 0.028** | 0.024 | 0.159*** | 0.270* | -0.025 | 0.000 | -0.006 | 0.012 |
| | (0.045) | (0.012) | (0.038) | (0.033) | (0.138) | (0.034) | (0.021) | (0.021) | (0.017) |
| Digital and intangible variable (manufacturing) | 0.068 | 0.028* | 0.027 | -0.049 | 1.180 | 0.125** | 0.011 | 0.043 | 0.017 |
| | (0.097) | (0.015) | (0.069) | (0.357) | (1.440) | (0.050) | (0.021) | (0.031) | (0.025) |
| Constant | -0.347*** | -0.229*** | -0.351*** | -0.307*** | -0.305*** | -0.234*** | -0.233*** | -0.183*** | -0.216*** |
| | (0.026) | (0.019) | (0.024) | (0.026) | (0.027) | (0.021) | (0.021) | (0.046) | (0.033) |
| Time fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Sector fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 3,367 | 5,516 | 3,418 | 2,868 | 2,868 | 5,527 | 5,531 | 1,689 | 2,663 |
| R-squared | 0.174 | 0.146 | 0.163 | 0.187 | 0.186 | 0.148 | 0.147 | 0.142 | 0.137 |

Note: The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Digital and intangible variable denotes variables shown in the first row: ICT hardware investment, broadband (>30Mbit/s), software investment, ICT specialist skills, software specialist skills, computer use at work, CRM and ERP front-office software, cloud computing, and big data analytics. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Main results highlighted.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

## Table C.3. Young firms versus incumbent firms

| VARIABLES | ICT infrastructure | | Intangibles including skills | | | | Digital technologies | | |
|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware investment | Broadband (>30Mbit/s) | Software investment | ICT specialist skills | Software specialist skills | Computer use at work | CRM/ ERP | Cloud computing | Big data |
| Frontier growth | 0.163*** | 0.164*** | 0.167*** | 0.176*** | 0.176*** | 0.166*** | 0.167*** | 0.102 | 0.190*** |
| | (0.023) | (0.021) | (0.023) | (0.030) | (0.030) | (0.022) | (0.022) | (0.062) | (0.038) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Gap to the frontier (lagged) | 0.271*** | 0.244*** | 0.270*** | 0.300*** | 0.300*** | 0.248*** | 0.248*** | 0.211*** | 0.213*** |
| | (0.019) | (0.021) | (0.019) | (0.026) | (0.026) | (0.022) | (0.022) | (0.038) | (0.031) |
| Capital per worker | 0.018*** | 0.015*** | 0.016*** | 0.016*** | 0.016*** | 0.015*** | 0.015*** | 0.008 | 0.013*** |
| | (0.004) | (0.004) | (0.004) | (0.005) | (0.005) | (0.004) | (0.004) | (0.005) | (0.004) |
| Firm size (medium-sized enterprise) | -0.033* | -0.033** | -0.033** | -0.032* | -0.032* | -0.031** | -0.031** | -0.034* | -0.032* |
| | (0.018) | (0.013) | (0.016) | (0.019) | (0.019) | (0.014) | (0.014) | (0.019) | (0.018) |
| Firm size (large enterprise) | -0.017 | -0.019 | -0.02 | -0.015 | -0.015 | -0.017 | -0.016 | -0.035 | -0.02 |
| | (0.022) | (0.017) | (0.018) | (0.021) | (0.022) | (0.018) | (0.018) | (0.027) | (0.023) |
| Manufacturing | 0.050*** | -0.047*** | 0.072*** | -0.002 | -0.002 | -0.043*** | -0.046*** | 0.009 | -0.075*** |
| | (0.015) | (0.014) | (0.013) | (0.029) | (0.029) | (0.016) | (0.015) | (0.022) | (0.021) |
| Young firm | 0.032* | 0.015 | 0.033* | 0.051** | 0.051** | 0.011 | 0.011 | -0.020 | -0.015 |
| | (0.018) | (0.013) | (0.017) | (0.020) | (0.021) | (0.013) | (0.013) | (0.025) | (0.026) |
| Digital and intangible variable (young firms) | 0.318** | 0.077** | 0.129 | 0.378** | 0.345** | -0.101 | -0.041 | -0.027 | 0.034 |
| | (0.152) | (0.032) | (0.107) | (0.159) | (0.160) | (0.089) | (0.068) | (0.081) | (0.028) |
| Digital and intangible variable (incumbent firms) | 0.131** | 0.022** | 0.008 | 0.132*** | 0.276 | 0.027 | 0.009 | 0.012 | 0.009 |
| | (0.055) | (0.010) | (0.027) | (0.039) | (0.190) | (0.025) | (0.014) | (0.019) | (0.015) |
| Constant | -0.361*** | -0.230*** | -0.365*** | -0.342*** | -0.342*** | -0.239*** | -0.237*** | -0.170*** | -0.185*** |
| | (0.021) | (0.017) | (0.020) | (0.023) | (0.023) | (0.017) | (0.017) | (0.042) | (0.024) |
| Time fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Sector fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 3,367 | 5,516 | 3,418 | 2,868 | 2,868 | 5,527 | 5,531 | 1,689 | 2,663 |
| R-squared | 0.175 | 0.146 | 0.164 | 0.188 | 0.187 | 0.148 | 0.147 | 0.141 | 0.136 |

Note: The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Digital and intangible variable denotes variables shown in the first row: ICT hardware investment, broadband (>30Mbit/s), software investment, ICT specialist skills, software specialist skills, computer use at work, CRM and ERP front-office software, cloud computing, and big data analytics. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Main results highlighted.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

## Table C.4. Effects by firm age

| VARIABLES | ICT infrastructure | | Intangibles including skills | | | | Digital technologies | | |
|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware investment | Broadband (>30Mbit/s) | Software investment | ICT specialist skills | Software specialist skills | Computer use at work | CRM/ ERP | Cloud computing | Big data |
| Frontier growth | 0.162*** | 0.164*** | 0.167*** | 0.174*** | 0.174*** | 0.167*** | 0.167*** | 0.102 | 0.191*** |
| | (0.022) | (0.021) | (0.023) | (0.030) | (0.030) | (0.022) | (0.022) | (0.062) | (0.038) |
| Gap to the frontier (lagged) | 0.271*** | 0.244*** | 0.270*** | 0.299*** | 0.299*** | 0.248*** | 0.248*** | 0.211*** | 0.214*** |
| | (0.019) | (0.021) | (0.019) | (0.026) | (0.026) | (0.022) | (0.022) | (0.038) | (0.031) |
| Capital per worker | 0.018*** | 0.015*** | 0.016*** | 0.016*** | 0.016*** | 0.015*** | 0.015*** | 0.008 | 0.013*** |
| | (0.004) | (0.004) | (0.004) | (0.005) | (0.005) | (0.004) | (0.004) | (0.005) | (0.004) |
| Firm age | -0.004 | -0.002 | -0.005 | -0.013* | -0.013* | -0.001 | -0.001 | 0.005 | 0.012 |
| | (0.005) | (0.005) | (0.005) | (0.007) | (0.007) | (0.005) | (0.005) | (0.008) | (0.008) |
| Firm size (medium-sized enterprise) | -0.032* | -0.033** | -0.032** | -0.030 | -0.030 | -0.031** | -0.031** | -0.036* | -0.033* |
| | (0.019) | (0.013) | (0.016) | (0.019) | (0.019) | (0.014) | (0.014) | (0.019) | (0.018) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Firm size (large enterprise) | -0.017 | -0.019 | -0.019 | -0.013 | -0.013 | -0.016 | -0.016 | -0.037 | -0.021 |
| | (0.022) | (0.017) | (0.018) | (0.022) | (0.022) | (0.018) | (0.018) | (0.027) | (0.023) |
| Manufacturing | 0.056*** | -0.039** | 0.076*** | 0.004 | 0.004 | -0.044*** | -0.045*** | 0.005 | -0.082*** |
| | (0.014) | (0.015) | (0.013) | (0.028) | (0.028) | (0.015) | (0.015) | (0.021) | (0.021) |
| Digital and intangible variable * firm age | 0.045*** | 0.008** | 0.006 | 0.050*** | 0.100 | 0.003 | 0.001 | 0.003 | 0.004 |
| | (0.016) | (0.004) | (0.010) | (0.013) | (0.062) | (0.009) | (0.004) | (0.005) | (0.005) |
| Constant | -0.352*** | -0.230*** | -0.351*** | -0.306*** | -0.306*** | -0.233*** | -0.233*** | -0.184*** | -0.216*** |
| | (0.025) | (0.019) | (0.024) | (0.027) | (0.027) | (0.021) | (0.021) | (0.046) | (0.033) |
| Time fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Sector fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 3,367 | 5,516 | 3,418 | 2,868 | 2,868 | 5,527 | 5,531 | 1,689 | 2,663 |
| R-squared | 0.172 | 0.146 | 0.162 | 0.186 | 0.186 | 0.147 | 0.147 | 0.141 | 0.137 |

Note: The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Digital and intangible variable denotes variables shown in the first row: ICT hardware investment, broadband (>30Mbit/s), software investment, ICT specialist skills, software specialist skills, computer use at work, ICT training, CRM and ERP front-office software, cloud computing, and big data analytics. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Main results highlighted.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

## Table C.5. Baseline specification using initial digital adoption and intangible intensity as IV

| VARIABLES | ICT infrastructure | | Intangibles including skills | | | | | Digital technologies | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware invest. | Broadband (>30 Mbit/s) | Software invest. | ICT specialist skills | Software specialist skills | Computer use at work | ICT training | CRM/ ERP | Cloud comput. | Big data |
| Frontier growth | 0.185*** | 0.171*** | 0.178*** | 0.156*** | 0.156*** | 0.155*** | 0.151*** | 0.172*** | 0.172*** | 0.169*** |
| | (0.027) | (0.023) | (0.026) | (0.035) | (0.035) | (0.024) | (0.033) | (0.024) | (0.047) | (0.027) |
| Gap to the frontier (lagged) | 0.263*** | 0.247*** | 0.260*** | 0.254*** | 0.253*** | 0.241*** | 0.257*** | 0.247*** | 0.278*** | 0.250*** |
| | (0.032) | (0.019) | (0.032) | (0.022) | (0.022) | (0.024) | (0.028) | (0.019) | (0.040) | (0.029) |
| Capital per worker | 0.017*** | 0.018*** | 0.013** | 0.018*** | 0.018*** | 0.015*** | 0.014*** | 0.018*** | 0.018*** | 0.013*** |
| | (0.006) | (0.005) | (0.005) | (0.005) | (0.005) | (0.004) | (0.005) | (0.005) | (0.006) | (0.004) |
| Firm age | -0.004 | -0.007 | -0.005 | -0.010 | -0.010 | -0.007 | -0.009 | -0.007 | -0.010 | 0.007 |
| | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) | (0.006) | (0.007) | (0.007) | (0.008) | (0.006) |
| Firm size (medium-sized enterprise) | -0.015 | -0.034 | -0.016 | -0.031* | -0.030* | -0.027* | -0.021 | -0.034 | -0.016 | -0.028 |
| | (0.029) | (0.024) | (0.027) | (0.016) | (0.016) | (0.014) | (0.014) | (0.024) | (0.021) | (0.022) |
| Firm size (large enterprise) | 0.007 | -0.030 | 0.000 | -0.027 | -0.026 | -0.009 | -0.007 | -0.030 | -0.006 | -0.013 |
| | (0.026) | (0.026) | (0.026) | (0.019) | (0.019) | (0.018) | (0.018) | (0.026) | (0.026) | (0.027) |
| Digital and intangible variable | 0.112** | 0.037*** | 0.005 | 0.136*** | 0.139* | 0.001 | 0.034** | -0.003 | 0.005 | 0.008 |
| | (0.048) | (0.014) | (0.033) | (0.049) | (0.081) | (0.026) | (0.014) | (0.019) | (0.018) | (0.015) |
| Constant | -0.254*** | -0.247*** | -0.252*** | -0.248*** | -0.248*** | -0.251*** | -0.264*** | -0.248*** | -0.257*** | -0.293*** |
| | (0.037) | (0.034) | (0.034) | (0.036) | (0.036) | (0.035) | (0.040) | (0.035) | (0.063) | (0.036) |
| Time fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Sector fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1,764 | 3,076 | 1,774 | 2,528 | 2,528 | 3,805 | 3,146 | 3,080 | 2,170 | 3,292 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| R-squared | 0.216 | 0.164 | 0.211 | 0.176 | 0.174 | 0.143 | 0.161 | 0.162 | 0.198 | 0.140 |

Note: The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Digital and intangible variable denotes variables shown in the first row: ICT hardware investment, broadband (>30Mbit/s), software investment, ICT specialist skills, software specialist skills, computer use at work, ICT training, CRM and ERP front-office software, cloud computing, and big data analytics. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity. Specifically, exposure is based on sector-wide means of digital and intangible measures and initial firm-level digital and intangible measures in 2012. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Main results highlighted.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

## Table C.6. Baseline specification using multifactor productivity as dependent variable

| VARIABLES | ICT infrastructure | | Intangibles including skills | | | | Digital technologies | | |
|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware invest. | Broadband (>30Mbit/s) | Software invest. | ICT specialist skills | Software specialist skills | Computer use at work | CRM/ ERP | Cloud computing | Big data |
| Frontier growth | 0.121** | 0.130** | 0.126** | 0.163*** | 0.164*** | 0.132** | 0.112 | 0.133** | 0.161* |
| | (0.057) | (0.051) | (0.054) | (0.045) | (0.045) | (0.052) | (0.078) | (0.051) | (0.093) |
| Gap to the frontier (lagged) | 0.171*** | 0.162*** | 0.160*** | 0.202*** | 0.201*** | 0.164*** | 0.158** | 0.163*** | 0.094** |
| | (0.034) | (0.031) | (0.036) | (0.037) | (0.037) | (0.032) | (0.070) | (0.031) | (0.037) |
| Firm age | -0.012 | -0.013 | -0.009 | -0.010 | -0.011 | -0.013 | 0.004 | -0.013 | -0.004 |
| | (0.008) | (0.008) | (0.008) | (0.010) | (0.010) | (0.008) | (0.011) | (0.008) | (0.022) |
| Firm size (medium-sized enterprise) | -0.026 | -0.024 | -0.029 | -0.051 | -0.050 | -0.020 | -0.027 | -0.022 | -0.056 |
| | (0.034) | (0.033) | (0.035) | (0.032) | (0.033) | (0.032) | (0.046) | (0.033) | (0.121) |
| Firm size (large enterprise) | -0.034 | -0.044 | -0.037 | -0.065** | -0.062* | -0.038 | -0.04 | -0.041 | -0.074 |
| | (0.033) | (0.031) | (0.035) | (0.031) | (0.032) | (0.031) | (0.036) | (0.031) | (0.103) |
| Digital and intangible variable | 0.091** | 0.061*** | 0.011 | 0.140* | 0.388*** | 0.031 | 0.049 | -0.011 | -0.047** |
| | (0.045) | (0.023) | (0.039) | (0.077) | (0.144) | (0.050) | (0.038) | (0.029) | (0.023) |
| Constant | -0.436*** | -0.425*** | -0.450*** | -0.535*** | -0.533*** | -0.441*** | -0.439* | -0.437*** | -0.242 |
| | (0.092) | (0.089) | (0.105) | (0.108) | (0.109) | (0.090) | (0.242) | (0.090) | (0.155) |
| Time fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Sector fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1,269 | 1,460 | 1,283 | 1,168 | 1,168 | 1,460 | 573 | 1,462 | 347 |
| R-squared | 0.177 | 0.151 | 0.166 | 0.189 | 0.190 | 0.147 | 0.152 | 0.146 | 0.227 |

Note: The dependent variable is multifactor productivity (MFP) growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). MFP is calculated using the Wooldridge (2009) methodology and excludes investment in software and hardware to avoid endogeneity concerns. Digital and intangible variable denotes variables shown in the first row: ICT hardware investment, broadband (>30Mbit/s), software investment, ICT specialist skills, software specialist skills, computer use at work, ICT training, CRM and ERP front-office software, cloud computing, and big data analytics. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Main results highlighted.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

## Table C.7. Baseline specification using robust productivity frontier

| VARIABLES | ICT infrastructure | | Intangibles including skills | | | | Digital technologies | | |
|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware invest. | Broadband (>30Mbit/s) | Software invest. | ICT specialist skills | Software specialist skills | Computer use at work | CRM/ ERP | Cloud computing | Big data |
| Robust frontier growth | 0.099** | 0.120*** | 0.126** | 0.235*** | 0.234*** | 0.124*** | 0.233*** | 0.123*** | 0.153** |
| | (0.048) | (0.041) | (0.051) | (0.072) | (0.072) | (0.041) | (0.072) | (0.041) | (0.064) |
| Gap to the robust frontier (lagged) | 0.280*** | 0.281*** | 0.284*** | 0.364*** | 0.363*** | 0.287*** | 0.363*** | 0.286*** | 0.226*** |
| | (0.063) | (0.050) | (0.068) | (0.080) | (0.080) | (0.050) | (0.081) | (0.050) | (0.029) |
| Capital per worker | 0.014*** | 0.012*** | 0.011*** | 0.014*** | 0.013*** | 0.012*** | 0.013*** | 0.012*** | 0.005 |
| | (0.004) | (0.004) | (0.004) | (0.005) | (0.005) | (0.004) | (0.005) | (0.004) | (0.004) |
| Firm age | 0.002 | 0.005 | -0.001 | -0.003 | -0.004 | 0.006 | -0.004 | 0.006 | 0.006 |
| | (0.006) | (0.006) | (0.006) | (0.010) | (0.010) | (0.006) | (0.010) | (0.006) | (0.010) |
| Firm size (medium-sized enterprise) | -0.026 | -0.032** | -0.025 | -0.043 | -0.042 | -0.030* | -0.042 | -0.030* | -0.040* |
| | (0.019) | (0.015) | (0.018) | (0.026) | (0.026) | (0.015) | (0.026) | (0.015) | (0.020) |
| Firm size (large enterprise) | -0.022 | -0.013 | -0.018 | -0.012 | -0.012 | -0.010 | -0.012 | -0.010 | -0.043 |
| | (0.022) | (0.018) | (0.020) | (0.028) | (0.028) | (0.019) | (0.028) | (0.019) | (0.026) |
| Digital and intangible variable | 0.161*** | 0.034*** | 0.009 | 0.189*** | 0.366** | 0.052 | 0.027 | 0.007 | 0.016 |
| | (0.045) | (0.011) | (0.038) | (0.064) | (0.182) | (0.034) | (0.019) | (0.023) | (0.016) |
| Constant | -0.278*** | -0.253*** | -0.229*** | -0.278*** | -0.277*** | -0.264*** | -0.276*** | -0.262*** | -0.170*** |
| | (0.062) | (0.049) | (0.064) | (0.075) | (0.075) | (0.049) | (0.075) | (0.049) | (0.050) |
| Time fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Sector fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 2,872 | 4,721 | 2,926 | 2,087 | 2,087 | 4,733 | 2,087 | 4,736 | 1,682 |
| R-squared | 0.151 | 0.151 | 0.151 | 0.208 | 0.207 | 0.153 | 0.206 | 0.152 | 0.142 |

Note: The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Robust productivity frontier is based on the 2-year moving average log labour productivity for the top 5% of companies with the highest productivity levels in each 2-digit industry and year. Digital and intangible variable denotes variables shown in the first row: ICT hardware investment, broadband (>30Mbit/s), software investment, ICT specialist skills, software specialist skills, computer use at work, ICT training, CRM and ERP front-office software, cloud computing, and big data analytics. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Main results highlighted.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

## Table C.8. Baseline specification controlling for sector-year fixed effects

| VARIABLES | ICT infrastructure | | Intangibles including skills | | | | | Digital technologies | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware invest. | Broadband (>30Mbit/s) | Software invest. | ICT specialist skills | Software specialist skills | Computer use at work | ICT training | CRM/ ERP | Cloud comput. | Big data |
| Frontier growth | 0.110*** | 0.115*** | 0.113*** | 0.131*** | 0.132*** | 0.117*** | 0.105*** | 0.117*** | 0.084** | 0.112*** |
| | (0.021) | (0.020) | (0.020) | (0.028) | (0.028) | (0.020) | (0.025) | (0.020) | (0.034) | (0.022) |
| Gap to the frontier (lagged) | 0.192*** | 0.171*** | 0.187*** | 0.206*** | 0.206*** | 0.174*** | 0.193*** | 0.174*** | 0.154*** | 0.149*** |
| | (0.015) | (0.018) | (0.016) | (0.025) | (0.025) | (0.019) | (0.023) | (0.019) | (0.027) | (0.024) |
| Capital per worker | 0.008** | 0.005* | 0.005* | 0.006* | 0.006 | 0.005* | 0.006 | 0.005* | 0.003 | 0.004 |
| | (0.003) | (0.003) | (0.003) | (0.004) | (0.004) | (0.003) | (0.004) | (0.003) | (0.004) | (0.003) |
| Firm age | -0.002 | -0.001 | -0.001 | -0.010 | -0.010 | 0.000 | -0.005 | 0.000 | 0.006 | 0.013* |
| | (0.005) | (0.005) | (0.005) | (0.008) | (0.008) | (0.005) | (0.010) | (0.005) | (0.007) | (0.007) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Firm size (medium-sized enterprise) | -0.014 | -0.018 | -0.016 | -0.004 | -0.003 | -0.016 | -0.005 | -0.016 | -0.018 | -0.027 |
| | (0.013) | (0.012) | (0.015) | (0.018) | (0.018) | (0.013) | (0.022) | (0.013) | (0.018) | (0.017) |
| Firm size (large enterprise) | 0.003 | -0.001 | 0.002 | 0.019 | 0.020 | 0.001 | 0.032 | 0.002 | -0.011 | -0.016 |
| | (0.017) | (0.015) | (0.017) | (0.018) | (0.018) | (0.016) | (0.023) | (0.016) | (0.022) | (0.022) |
| Digital and intangible variable | 0.150*** | 0.026*** | 0.026 | 0.152*** | 0.300** | 0.006 | 0.006 | 0.001 | 0.008 | 0.015 |
| | (0.041) | (0.009) | (0.033) | (0.033) | (0.143) | (0.031) | (0.019) | (0.017) | (0.018) | (0.014) |
| Constant | -0.137*** | -0.119*** | -0.118*** | -0.144*** | -0.144*** | -0.127*** | -0.172*** | -0.127*** | -0.121*** | -0.126*** |
| | (0.040) | (0.031) | (0.032) | (0.040) | (0.040) | (0.033) | (0.037) | (0.033) | (0.040) | (0.042) |
| Sector-year fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 3,367 | 5,516 | 3,418 | 2,868 | 2,868 | 5,527 | 2,067 | 5,531 | 1,689 | 2,663 |
| R-squared | 0.120 | 0.100 | 0.109 | 0.119 | 0.119 | 0.101 | 0.095 | 0.101 | 0.086 | 0.092 |

Note: The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Digital and intangible variable denotes variables shown in the first row: ICT hardware investment, broadband (>30Mbit/s), software investment, ICT specialist skills, software specialist skills, computer use at work, ICT training, CRM and ERP front-office software, cloud computing, and big data analytics. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Main results highlighted.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

## Table C.9. Accounting for skill shortages

| VARIABLES | ICT infrastructure | | Intangibles including skills | | | | Digital technologies | | |
|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware invest. | Broadband (>30Mbit/s) | Software invest. | ICT specialist skills | Software specialist skills | Computer use at work | CRM/ ERP | Cloud computing | Big data |
| Frontier growth | 0.161*** | 0.164*** | 0.166*** | 0.173*** | 0.173*** | 0.166*** | 0.167*** | 0.097 | 0.189*** |
| | (0.023) | (0.022) | (0.023) | (0.030) | (0.030) | (0.022) | (0.022) | (0.061) | (0.036) |
| Gap to the robust frontier (lagged) | 0.272*** | 0.244*** | 0.270*** | 0.300*** | 0.300*** | 0.248*** | 0.248*** | 0.211*** | 0.214*** |
| | (0.019) | (0.021) | (0.019) | (0.026) | (0.026) | (0.022) | (0.022) | (0.038) | (0.031) |
| Capital per worker | 0.018*** | 0.015*** | 0.016*** | 0.016*** | 0.016*** | 0.015*** | 0.015*** | 0.008 | 0.013*** |
| | (0.004) | (0.004) | (0.004) | (0.005) | (0.005) | (0.004) | (0.004) | (0.005) | (0.004) |
| Firm age | -0.005 | -0.002 | -0.005 | -0.013* | -0.013* | -0.001 | -0.001 | 0.006 | 0.012 |
| | (0.006) | (0.005) | (0.005) | (0.007) | (0.007) | (0.005) | (0.005) | (0.008) | (0.008) |
| Firm size (medium-sized enterprise) | -0.032* | -0.033** | -0.032** | -0.030 | -0.029 | -0.031** | -0.031** | -0.035* | -0.034* |
| | (0.018) | (0.013) | (0.016) | (0.019) | (0.019) | (0.014) | (0.014) | (0.019) | (0.017) |
| Firm size (large enterprise) | -0.017 | -0.019 | -0.019 | -0.014 | -0.013 | -0.016 | -0.016 | -0.036 | -0.021 |
| | (0.022) | (0.016) | (0.018) | (0.021) | (0.021) | (0.018) | (0.018) | (0.027) | (0.023) |
| Skill shortages | 0.229 | 0.129 | 0.154 | 0.262 | 0.267 | 0.144 | 0.130 | -0.119 | 0.168 |
| | (0.179) | (0.130) | (0.176) | (0.313) | (0.313) | (0.141) | (0.128) | (0.245) | (0.194) |
| Digital and intangible variable | 0.152*** | 0.028*** | 0.024 | 0.154*** | 0.288* | 0.009 | 0.002 | 0.007 | 0.013 |
| | (0.042) | (0.010) | (0.034) | (0.033) | (0.147) | (0.031) | (0.017) | (0.018) | (0.014) |
| Constant | -0.304*** | -0.274*** | -0.281*** | -0.319*** | -0.319*** | -0.283*** | -0.283*** | -0.171*** | -0.313*** |
| | (0.035) | (0.029) | (0.033) | (0.043) | (0.044) | (0.032) | (0.032) | (0.057) | (0.050) |
| Time fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Sector fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 3,367 | 5,516 | 3,418 | 2,868 | 2,868 | 5,527 | 5,531 | 1,689 | 2,663 |
| R-squared | 0.174 | 0.146 | 0.163 | 0.187 | 0.187 | 0.147 | 0.147 | 0.141 | 0.137 |

Note: The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Digital and intangible variable denotes variables shown in the first row: ICT hardware investment, broadband (>30Mbit/s), software investment, ICT specialist skills, software specialist skills, computer use at work, ICT training, CRM and ERP front-office software, cloud computing, and big data analytics. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Main results highlighted.
Source: Authors' calculations based on business survey data from Statistics Netherlands.

## Table C.10. Small versus large firms

| VARIABLES | **ICT infrastructure** | | **Intangibles including skills** | | | | **Digital technologies** | | |
|---|---|---|---|---|---|---|---|---|---|
| | ICT hardware invest. | Broadband (>30Mbit/s) | Software investment | ICT specialist skills | Software specialist skills | Computer use at work | CRM/ ERP | Cloud computing | Big data |
| Small firms | 0.165*** | 0.033* | 0.037 | 0.026*** | 0.061*** | -0.044 | -0.039 | 0.032* | 0.028 |
| Medium-sized firms | 0.141*** | 0.020** | 0.019 | 0.200*** | 0.374*** | 0.028 | 0.033 | -0.007 | 0.003 |
| Large firms | 0.160*** | 0.036* | 0.019 | 0.169*** | 0.267*** | 0.019 | -0.007 | 0.017 | 0.019 |

Note: The dependent variable is labour productivity growth of non-frontier firms (excl. top 5 percent firms in each sector-year cell). Results are based on estimates of IV regression presented in Eq. 4 of this paper, adding dummy variables that divide the sample by firm size. In addition, interaction terms of digital and intangible variables with firm size class dummies are included. Results for effects across firm size class show the combined effect of digital/intangible variables and the interaction of digital/intangible variables and firm size class dummies. Digital and intangible variable denotes variables shown in the first row: ICT hardware investment, broadband (>30Mbit/s), software investment, ICT specialist skills, software specialist skills, computer use at work, CRM and ERP front-office software, cloud computing, and big data analytics. In all models, digital and intangible variables are instrumented using exposure to sector-wide advances in digital adoption and intangible intensity. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' calculations based on business survey data from Statistics Netherlands.