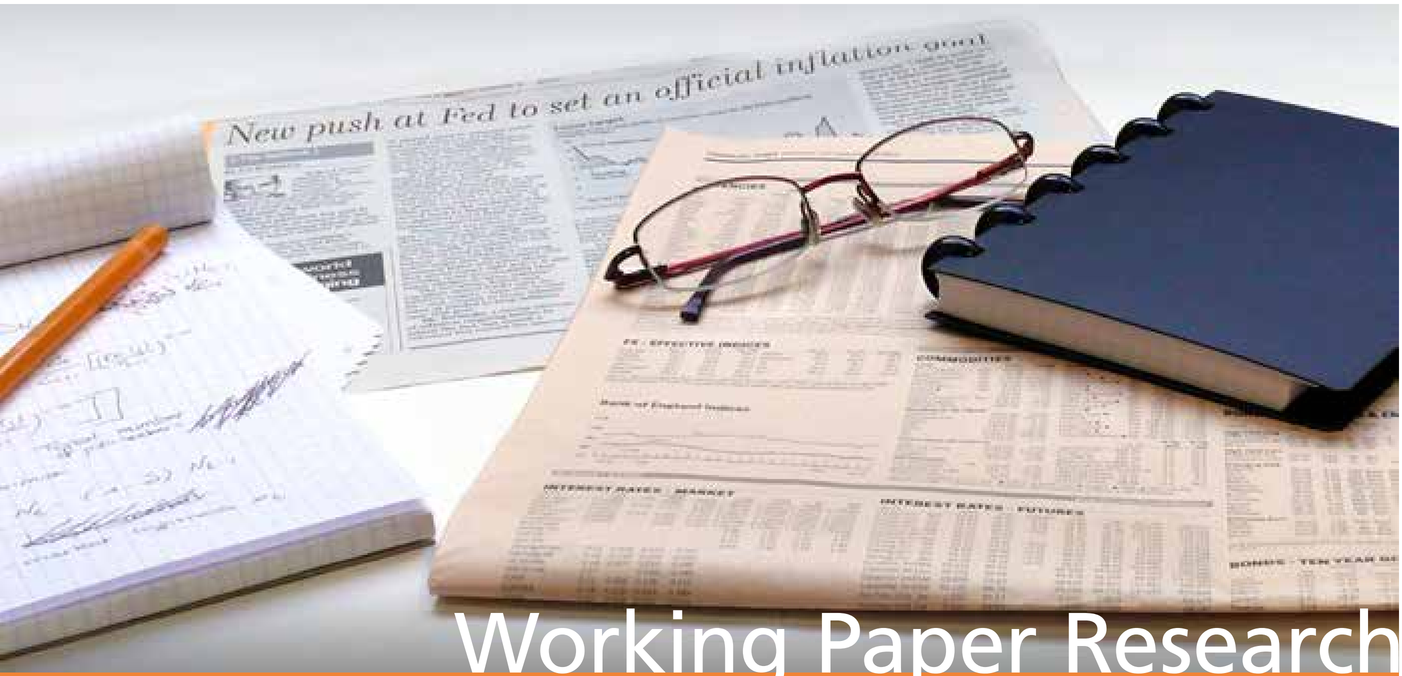
IT and productivity: A firm level analysis



Working Paper Research

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October 2018 No 346

NationalBank OF BELGIUM
Eurosystem

Editor

Jan Smets, Governor of the National Bank of Belgium

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ISSN: 1375-680X (print)
ISSN: 1784-2476 (online)

Abstract

Using a novel comprehensive data set of IT investment at the firm level, we find that a firm investing an additional euro in IT increases value added by 1 euro and 38 cents on average. This marginal product of IT investment increases with firm size and varies across sectors. IT explains about 10% of productivity dispersion across firms. While we find substantial returns of IT at the firm level, such returns are much lower at the aggregate level. This is due to underinvestment in IT (IT capital deepening is low) and misallocation of IT investments.

JEL codes: D24, L10, O14, O49

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We thank two anonymous referees of the NBB for comments and reviewing an earlier version of the paper. Furthermore, we would like to thank Todd Gerarden, Ariell Reshef, Mark Roberts, Fabiano Schivardi and Jakob Vanschoonbeek for useful comments and suggestions. We also thank the participants at the EEA 2018 in Cologne, IIOC 2018 in Indianapolis, the OECD-IZA 2017 Workshop in Paris, EARIE 2017 in Maastricht, CISS 2017 in Sardinia and VIVES seminar in Leuven. Financial support of FWO grant G055914N and the 'Econopolis Chair' on firm growth is gratefully acknowledged. The results presented in this paper comply with the legal rules on statistical secrecy.

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1. Introduction

In recent years, most industrial economies have witnessed a slowdown in productivity growth. Yet, societies are increasingly transformed by the introduction of computers, robots and more in general the adaption of information and communication technology (IT), which is believed to increase production efficiency. For instance, Hubbard (2003) shows how on-board computers improve monitoring in the trucking industry, raising average utilization rates of trucks. In the insurance industry, contract enforceability can be improved thanks to computer enabled monitoring devices (Varian, 2010). More general research on linking IT capital to both 'IT producing' and 'IT using industries' suggests that much of the aggregate U.S. productivity growth in the 1990s can be explained by the rapid growth in especially the 'IT producing', but to a lesser extent in the 'IT using' ones (Jorgenson, Ho and Stiroh, 2005; 2008). However, this stands in sharp contrast with the recent aggregate productivity statistics, both in the U.S. and Europe. While there is some evidence that information technology (IT) has triggered a process of job polarization due to increased automation of encodable tasks, making workers carrying out routine tasks redundant (e.g. Goos, Manning and Salomon, 2014), aggregate productivity growth does not seem to be affected. In fact, Acemoglu et al. (2014) find that output even contracts in IT-intensive industries in the U.S. Also Carr (2003) argues that IT is just a commodity factor of production and Gordon (2010) argues that business productivity improvements from IT are already in the past. On the other hand, Brynjolfsson and McAfee (2014) claim that most of the productivity gains from IT are still to come. This paper analyzes how IT capital at the firm level has an impact on firm level productivity. In doing so, we make a number of contributions to this literature.

In particular, despite the widespread academic and political interest in the relationship between productivity growth and IT, it remains challenging to pin down this relationship. An important challenge is the measurement of IT, which is mostly only available at a high level of aggregation, either the 2 or 3-digit sector level. Moreover, in most of the literature IT typically refers to broad investments in office and computing investment and therefore does not capture precisely the extent of technological change, which may also be induced by software and communications technology, especially the last decade.[5] Furthermore, heterogeneity between firms in term of productivity growth, even within narrowly defined sectors, is substantial and cannot be captured at the sector level (Syverson, 2004). While some firms within the same sector may experience productivity gains triggered by IT, other firms not adapting IT, may see productivity losses and as a result aggregate productivity effects may seem unaffected by IT.

This paper therefore first develops a measure of IT investment at the firm level, which improves on earlier ones used in the literature. To this end, we use a data set which allows us to trace all IT purchases by firms. In addition, we use import data at the product-firm level to capture IT purchases from abroad. This allows us to construct an accurate firm specific measure of IT investments. Earlier work using firm level

[5] Notable exceptions are Aral, Brynjolfsson and Wu (2006) who show that different types of IT investments have different effects on firm performance and the work of Bharadwaj (2000) and Aral and Weill (2007) who argue that alignment between IT investment allocations and strategy is crucial for attaining effects on firm performance.

measures of IT often relied on survey data or limited samples of large firms and is therefore subject to sample selection bias (e.g. Bharadwaj, Bharadwaj and Konsynski, 1999; Brynjolfsson and Hitt, 2003; Bloom, Draca, Kretschmer, Sadun and Van Reenen, 2010; Bloom, Sadun and Van Reenen, 2012). In contrast, our data set covers the entire firm size distribution, both small and large, and is obtained from VAT listings and declarations that firms are by law required to file, which implies our findings are robust to selection bias. We answer a number of questions which earlier work could not resolve adequately. For instance, it is likely that the returns of IT depends on firm size. In particular, as Bloom et al. (2012) show IT is complementary to management practices and as large firms have better management practices, the impact of IT investments could be larger for these firms. We find indeed that large firms benefit more from IT than small firms. This effect is not due to differences in the composition of IT capital and remains when adding controls for labor quality and firm fixed effects.

Second, the rich panel data structure of the data set allows us as well to use recent advances in the productivity literature to control for the endogeneity of IT investments. We use firm level company accounts data, which all firms by law have to submit to the National Bank of Belgium, and merge them with our measure of IT investments. To estimate productivity, we use a control function approach as introduced by Olley and Pakes (1996), in which IT capital is treated as a state variable, taking into account the potential endogeneity of IT. More specifically, we will follow Brynjolfsson and Hitt (1995, 2003) and estimate an augmented production function with IT capital and non-IT capital inputs and use the control function approach of Ackerberg, Caves and Frazer (2015) and a novel estimator recently introduced by Collard-Wexler and De Loecker (2016) that also controls for measurement error in capital.

Furthermore, we revisit the Solow paradox. We see IT capital contributing to output, and this effect is not only confined to the IT producing and IT using industries. To see whether these findings can be reconciled with the limited impact of IT at the macro-level, we compute aggregate productivity growth from our micro-level data set and use the decomposition introduced by Petrin and Levinsohn (2012). Our results indicate that this paradox can be explained by two causes: (i) too low IT investments and (ii) misallocation of IT investments. We find these effects to be particularly apparent after the great recession, which indicates that IT is a piece of the productivity puzzle of the last decade.

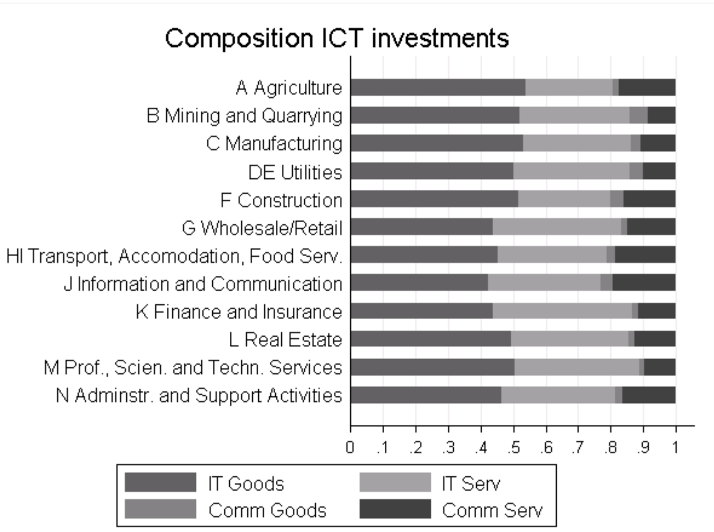
Finally, we investigated the impact of IT on TFP dispersion. We find that IT investments explain about 10 percent of the dispersion in measured productivity. Taking into account measurement error in firm level TFP, IT and human capital explain 30 to 40 percent of the dispersion in TFP in the Belgian economy.

The rest of the paper is organized as follows. In the next section we discuss how we construct our measure of IT and describe the various data sets that we use. Section 3 explains our econometric model and the control function approach that we use. Section 4 discusses the results and section 5 concludes.

2. Data

We combine four different data sets, available within the National Bank of Belgium, to obtain a firm level measure of IT capital and to estimate its impact on productivity. The first one covers a subset of the inter-firm transactions data set described in Dhyne, Magerman and Rubinova (2015). For this paper, we only consider the subset of transactions involving the purchase of IT products or services, either as IT capital goods or as IT consumables, by all Belgian firms. Based on the detailed four digit primary NACE sector code of the supplier, we distinguish investments in IT. We can differentiate between IT goods and IT services within these purchases, but not whether the purchase is tangible or intangible. For example, if a firm makes a purchase from a supplier that has its primary activity in sector 4651 – *Wholesale of Computers and Software* - we classify this purchase as an investment in IT.[6] In particular, we classify IT investments as purchases from firms active in the following narrowly defined 4-digit sectors. For IT goods: *2620 Computer and peripheral equipment, 4651 Wholesale of computers and software, 4741 Retail sale of computers and software* and *5829 Other software publishing* and for IT services: *6200-6203, 6209 Computer Programming, consultancy and related activities* and *6311-6312 Data processing, hosting and related services* (also see appendix E). We excluded all purchases related to communication technologies as well as information related services for our main analysis, but we show that our results are robust to taking these into account.[7] Figure 1 shows that in most sectors the IT component of goods and services accounts for about 80% of total ICT purchases, while communication goods hardly matter.

FIGURE 1: COMPOSITION OF ICT INVESTMENTS BY SECTOR



Source: Own calculations based on IT purchases data

[6] A breakdown of each purchase which shows how much of the IT purchase are investments and how much are intermediate inputs, is unfortunately not available. Appendix B provides further information on the data structure, the methodology that was applied to construct the IT capital stock and potential pitfalls.

[7] These include suppliers active in the following product branches: Communication equipment (2630), Wholesale trade of electronic and telecom equipment (4652), Retail trade of telecom equipment (4742) and Telecommunications activities (6110, 6120, 6130, 6190).

The second data set contains imports at the firm-product level and comes from the customs for imports coming outside the EU and the Intrastat trade survey for imports to Belgium coming from within the EU. We use this data to measure purchases of non-domestic IT goods. We do this based on the detailed HS 8 digit codes.

The third data set are VAT declarations, which provide total investment and total intermediate inputs consumption at the firm level. Coupled with the inter-firm transactions data set, this allows to compute IT and non-IT investment flows, from which we can construct IT capital stocks and non-IT capital stocks following the Perpetual Inventory Method. Appendix B provides more information on the IT purchases data, how the IT and non-IT capital stocks are constructed and presents IT intensity measures to show that our IT measure behaves as expected. Appendix C contains various robustness checks on the choices that we make in this process.

The fourth data set consists of the annual company accounts with detailed financial and operational data, which we use to estimate production functions. All incorporated firms in Belgium are required to submit company accounts to the National Bank of Belgium. We merge these four data sets, which results in 2 million firm-year observations, of which around 50% have positive investment in IT. We have data for the period 2002-2013 for the whole private sector, excluding the financial sector for which the company accounts are not available under the same format as non-financial firms.

Table 1 provides summary statistics of the main firm level variables that we use in our analysis and that report the necessary variables for the estimations. The panel consists of 996,955 firm-year observations over the period 2002-2013. The average firm employs 15.7 full time equivalent workers in our sample, but we have very small firms as well as very large firms with more than 10,000 workers. We will exploit these size differences in our analysis. Average value added is equal to 1.35 million EUR, implying labor productivity in the average firm to be around 85 thousand EUR. The average non-IT and IT capital stock are equal to 1.12 million EUR and 98 thousand EUR respectively. This means that an employee in the average firm has around 6,260 EUR IT capital to work with. The standard deviation is high, which indicates there are large differences at the firm level in the IT capital stock. So the aggregate picture hides a lot of firm level heterogeneity.

TABLE 1: SUMMARY STATISTICS (IN 2010 EUROS)

	mean	median	standard deviation
Value Added (X1000 €)	1,345	200	19,300
Non-IT Capital (X1000 €)	1,121	128	27,800
IT capital (X1000 €)	98.3	5.5	2,546
Employment	15.7	3	196
Non-IT Investment (X1000 €)	192	10	4,642
IT investment (X1000 €)	33	1.6	880

3. Econometric Model

In order to estimate the return from IT, we rely on an augmented Cobb Douglas production function. Tambe & Hitt (2012) adapt this production function by distinguishing between IT labor and non-IT labor. We take a similar approach and distinguish between IT capital and non-IT capital. By considering IT capital as a separate input in the production function next to non-IT capital, our approach is closest to the work of Brynjolfsson & Hitt (1996, 2003), Dewan & Kraemer (2000) and Bloom et al. (2012), with the advantage that our sample of firms is much larger, contains both small and large firms and does not rely on survey data. Also, we add robustness checks that allow for endogenous productivity growth, alternative data generating processes and mismeasurement in the capital stocks.

Our augmented production function treats IT capital and non-IT capital as separate inputs. The log-linearized Cobb-Douglas production function then looks as follows[8]:

$$y_{it} = \beta_l l_{it} + \beta_{IT} k_{it}^{IT} + \beta_{NIT} k_{it}^{NIT} + \omega_{it} + \epsilon_{it} \qquad (1)$$

In which the i and t subscripts refer to firm and year. y_{it} refers to log value added in firm i at time t.[9] l_{it}, k_{it}^{IT} and k_{it}^{NIT} refer respectively to the log labor, IT capital and non-IT capital stock and ω_{it} is the firm's log Total Factor Productivity (TFP). Econometricians do not observe a firm's TFP. This gives rise to the well-known simultaneity bias (Marschak & Andrews, 1944), i.e. firms typically adjust their capital and labor inputs in function of their productivity and this prevents one from obtaining unbiased estimates for β_l, β_{IT} and β_{NIT} with an OLS estimation of equation (1). To overcome this simultaneity bias, we use a semiparametric estimator. This approach was introduced by Olley & Pakes (1996, henceforth OP), the idea is to control for the unobserved productivity residual with other variables through which firms signal their productivity. The OP model relies on the firm's investment demand to control for the unobserved productivity. Levinsohn & Petrin (2003, henceforth LP) rely on the demand for material inputs instead of investment demand to proxy for unobserved productivity because investments are lumpy and often equal to zero. Ackerberg, Caves and Frazer (2015, henceforth ACF) discuss how to ensure unbiased identification of the OP and LP estimators. Collard-Wexler and De Loecker (2016, henceforth CWDL) build on these models and propose an estimator that relies on the firm's materials demand to proxy for unobserved productivity and that is robust to measurement error in capital. We use and modify the ACF estimator, which is currently the workhorse model in the literature. We also use the novel estimator introduced by CWDL. For consistency, we rely on material demand in both estimators.[10]

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[8] Dewan and Min (1997) showed that the Cobb Douglas production function is a good approximation of the actual underlying production function in the IT and productivity context. They found that the Translog and CES-translog production functions yield virtually identical estimates for the IT capital output elasticity and that the elasticities of substitution between IT and non-IT inputs are estimated to be very close to unity, consistent with the Cobb-Douglas model.

[9] We also experimented with gross output production functions that include materials as additional input and our findings are robust.

[10] We also experimented with a control function with non-IT investment as proxy variable, this did not change our findings regarding the output elasticity of IT capital.

The ACF estimation is based on the assumption that material expenditures are monotonically increasing in productivity, conditional on the other state variables. We can then substitute ω_{it} in equation (1) with the inverse of a non-parametric function of materials and the state variables, $\omega_{it} = f^{-1}(k_{it}^{IT}, k_{it}^{NIT}, l_{it}, m_{it})$. In a first step, we estimate the following equation:

$$\begin{aligned} y_{it} &= \beta_l l_{it} + \beta_{IT} k_{it}^{IT} + \beta_{NIT} k_{it}^{NIT} + f^{-1}(k_{it}^{IT}, k_{it}^{NIT}, l_{it}, m_{it}) + \epsilon_{it} \\ &= \tilde{\phi}_t(l_{it}, k_{it}^{IT}, k_{it}^{NIT}, m_{it}) + \epsilon_{it} \end{aligned} \quad (2)$$

In which m_{it} refers to material expenditures of firm i in year t. From this first step, we can only retrieve an estimate for value added, purified from ϵ_{it}, the true orthogonal residual that represents e.g. measurement error or machine breakdowns. In a second step we identify the input coefficients. Therefore, we introduce the second assumption that productivity evolves according to an exogenous first order Markov process (we relax this assumption in table A-9 of appendix C). Productivity is then a function of its lagged value and an unexpected shock:

$$\omega_{it} = g(\omega_{it-1}) + \xi_{it} \quad (3)$$

The parameters of the production function are identified from using the following moment conditions on this unexpected shock in productivity:

$$E\left[(\xi_{it})\begin{pmatrix} l_{it} \\ k_{it}^{IT} \\ k_{it}^{NIT} \end{pmatrix}\right] = 0 \quad (4)$$

Practically, we can compute from each candidate vector of input coefficients an estimate for ω_{it} which we non-parametrically regress on ω_{it-1} to obtain an estimate for ξ_{it}. We then construct the sample analogue of (4) and estimate the input coefficients by minimizing this sample analogue.

These moment conditions are the result of assumptions on the timing of the input decisions. First, as is common in the literature, we assume that it takes one year to order and install capital goods. Consequently, investments entering the capital stock in period t were decided based on the information available in year $t-1$ and are by definition unrelated to the unexpected productivity shocks in t. Second, we make a similar assumption for labor, namely that it takes one period to hire new workers. This is a more strict assumption than is common in the literature, but can be justified by the large extent of hiring and firing costs in Belgium (see as well Konings and Vanormelingen, 2015) and can lead to more precise estimates (Ackerberg et al., 2015). We also estimated the production function while allowing IT investments to be dependent on contemporaneous shocks in productivity as these are likely to be more flexible than non-IT capital investments. To this end, we replace k_{it}^{IT} by its lagged value in the moment conditions (see table A-8 in appendix C).

In a recent paper, CWDL argue that capital stocks are particularly sensitive to measurement error. First, when constructing the capital stock using the PIM method, we assumed a common depreciation rate for all firms while this probably varies across firms and vintage of the capital stock. Second, since we do not observe the initial capital stock, we approximated it using a measure for the IT capital intensity of the firm and the book value of all tangible fixed assets. This procedure is likely to introduce as well measurement error in the capital stock. CWDL propose a novel estimator that deals with this measurement error while controlling for unobserved productivity in the production function. To preserve the linear structure of the estimation equation, they suggest to write productivity as an AR(1) process. The counterpart of equation (2) with the CWDL extension is then:

$$y_{it} = \beta_l l_{it} + \beta_{IT} k_{it}^{IT} + \beta_{NIT} k_{it}^{NIT} + \theta_{IT} k_{it-1}^{IT} + \theta_{NIT} k_{it-1}^{NIT} + \theta_l l_{it-1} + \theta_m m_{it-1} + \xi_{it} + \epsilon_{it} \tag{5}$$

In which m_{it-1} refers to lagged material demand and the θ parameters combine the productivity persistence and production parameters. CWDL suggest to instrument the capital stock variables with lagged investments.[11] The idea is that the investment variables contain less measurement error than the stock variables. As explained in appendix B.1, we have detailed information on IT and non-IT investment flows. The following moment conditions are used for identification:

$$E\left[(\xi_{it} + \epsilon_{it})\begin{pmatrix} l_{it} \\ i_{it-1}^{IT} \\ i_{it-1}^{NIT} \\ i_{it-2}^{IT} \\ i_{it-2}^{NIT} \\ l_{it-1} \\ m_{it-1} \end{pmatrix}\right] = 0 \tag{6}$$

With i_{it}^{IT} and i_{it}^{NIT} the investments in IT capital and non-IT capital.[12] In our main specification, we model IT capital as a stock variable. The premise is that IT capital is part of the production isoquant, i.e. IT capital can be substituted with other production inputs. While this is the standard approach in the literature, it could be argued that IT investments induce a shift of the production function, i.e. enable to produce more output with the same set of inputs, for example because of new technology embedded in the IT goods. We enrich our model to allow for this data generating process as in Doraszelski and Jaumandreu (2013) and De Loecker (2013) in table A-9 of appendix C.

[11] Galuščák and Lízal (2011) propose a similar approach to account for measurement error in capital. Instead of investments, they instrument the capital stock with depreciation, employment and intermediate inputs.

[12] It is important to note that this procedure will correct for measurement error due to imprecisely observing the depreciation rate and the initial capital stock but not for measurement error in the investment variables themselves.

4. Results

4.1 Baseline results

Table 2 reports production function estimates for the private sector as a whole. All specifications control for industry and year fixed effects. The first column shows pooled OLS results. The second columns displays the ACF estimator. Lastly, we also report results for the CWDL estimator that corrects for measurement error in the capital variables.

TABLE 2: RESULTS PRIVATE SECTOR (NACE 1-82)

Value Added Production Function	OLS	ACF	CWDL
Labor	0.6783***	0.6289***	0.4923****
	(0.0015)	(0.0022)	(0.0061)
Non-IT Capital	0.1853***	0.2109***	0.3911***
	(0.0013)	(0.0019)	(0.0611)
IT Capital	0.0945***	0.1115***	0.1213***
	(0.0009)	(0.0014)	(0.0426)
# obs	996,955	839,946	330,567
Industry & Year FE	YES	YES	YES

Note: *** is significant at 1% level. Standard errors are clustered at the firm level. The number of observations for the CWDL estimation is substantially lower because it requires the first and second lag of investments in IT capital and non-IT capital while these are not required for the other estimators.

The output elasticities are reasonable and returns to scale are close to one. As expected, correcting for measurement error in the capital stocks with the CWDL estimator increases the capital coefficients. The direction in which the OLS, ACF and CWDL estimator change the estimates is consistent across different samples, e.g. applying OLS and ACF on the restricted CWDL sample gives qualitatively the same results (see table A-10 in appendix C). Yet, to maximally exploit the variance in the data, we show results based on the largest sample possible throughout the paper. The IT capital output elasticity is estimated in the range 0.09-0.12, so increasing the IT capital stock with 1% increases value added on average with 0.09-0.12%.[13] This is higher than in earlier work, see table A-1 in appendix A for a comparison with earlier studies.

While output elasticities have the advantage of being independent of the units in which outputs and inputs are measured, they cannot be easily compared with studies on other samples that have different average levels of IT investments or other factor input shares. Therefore, we follow Tambe and Hitt (2012) and Brynjolfsson et al. (1996) and compute the marginal product of the inputs.[14] The IT capital input share $\frac{K^{IT}}{VA}$ is on average 8.08% of value added, comparable to Brynjolfsson et al. (1995) who found an input share

[13] Or a 10% increase in IT capital multiplies value added with $e^{0.1115*\ln(1.1)} \approx 1.0107$. So a 10% increase in IT capital increases output with 1.07%

[14] The marginal product of IT capital is equal to the output elasticity of IT capital multiplied by the ratio of output to IT capital. Formally, $MP_{K^{IT}} = \frac{\delta Y}{\delta K^{IT}} = \frac{\delta Y}{\delta K^{IT}} \frac{K^{IT}}{Y} \frac{Y}{K^{IT}} = \beta_{IT} \frac{Y}{K^{IT}} = \frac{\beta_{IT}}{\frac{K^{IT}}{Y}}$. Estimates for β_{IT} are shown in Table 2. To obtain $\frac{K^{IT}}{Y}$, we use the same sample as for the estimation of the production function for consistency. We calculate the IT capital input share for each observation and take the mean of the resulting distribution after winsorizing at the 1% level to avoid bias from outliers.

of 9.35% for IT capital and IT labor together. Based on the estimated output elasticities of IT capital, $MP_{K^{IT}} = \beta_{IT}\left(\frac{K^{IT}}{Y}\right)^{-1} = \frac{0.1115}{0.0808} = 1.38$. So investing an additional euro in IT capital increases value added on average by one euro and 38 cents. For non-IT capital and labor, the input shares are respectively 1.09 and 0.0000189, so $MP_{K^{NIT}} = \frac{0.2109}{1.0943} = 0.19$ EUR and $MP_{\mathrm{L}} = \frac{0.6289}{0.0000189} \approx 33{,}000$ EUR.[15] Our estimates are higher than those of Brynjolfsson et al. (1996), who found the marginal product of IT capital to be 0.81 for a sample of 1121 large US firms. The marginal product learns how much the last dollar of IT capital contributes to value added. Infra-marginal investments generally have a higher rate of return, so our results indicate that the average return from investing in IT capital is even higher than 1.38. However, the net rate of return of IT capital also depends on the user costs that are associated to maintaining IT capital.[16] According to the EU KLEMS data, IT capital depreciates at a rate of 31.5% per year. Non-IT capital depreciation rates are lower and estimated between 5% and 15% per year. As a result, the net rate of return from IT capital is about $1.38 - 0.315 \approx 1.08$ while the net rate of return of non-IT capital is about $0.19 - 0.10 \approx 0.09$. Altogether, our results indicate excess returns from IT capital compared to non-IT capital. There can be multiple reasons for these, including adjustment costs and unmeasured complementary assets. Whatever the reason, an increase in IT capital would not only lead to increased output, but also to growth in (measured) multifactor productivity.

4.2 Industry Heterogeneity

As pointed out by Tambe and Hitt (2012), limited availability of data in earlier work prohibited sectoral comparisons. Our data contains information on firm level IT investments for the entire non-financial private sector. As shown in figure A-1, the results pooled over all sectors mask obviously important heterogeneity across sectors. Tables 3 and 4 show split sample results for manufacturing and services sectors as a first step in disentangling this heterogeneity.

TABLE 3: RESULTS MANUFACTURING SECTORS (NACE 10-33)

Value Added Production Function	OLS	ACF	CWDL
Labor	0.7235***	0.6640***	0.6126***
	(0.0042)	(0.0109)	(0.0169)
Non-IT Capital	0.1895***	0.2176***	0.2127**
	(0.0037)	(0.0144)	(0.1036)
IT Capital	0.0924***	0.1144***	0.1187*
	(0.0024)	(0.0056)	(0.0659)
# obs	138,507	127,680	58,826
Industry & Year FE	YES	YES	YES

Note: *** is significant at 1% level. ** is significant at 5% level. * is significant at 10% level. Standard errors are clustered at the firm level. The number of observations for the CWDL estimation is substantially lower because it requires the first and second lag of investments in IT capital and non-IT capital while these are not required for the other estimators.

[15] This is the marginal product of an additional full time equivalent. For comparison with the marginal products of capital, it is more convenient to compute MP_L from the wage bill input share: $MP_L = \frac{0.6289}{0.6529} = 0.96$. So investing an additional euro in labor, increases value added on average with 96 cents.

[16] The marginal product of an input is interpreted as its gross rate of return, whereas the net rate of return is defined as the marginal product minus the depreciation rate, as in Hall, Mairesse and Mohnen (2009).

TABLE 4: RESULTS SERVICES SECTORS (NACE 45-82)

Value Added Production Function	OLS	ACF	CWDL
Labor	0.6741***	0.6257***	0.4647***
	(0.0018)	(0.0043)	(0.0077)
Non-IT Capital	0.1749***	0.1990***	0.4209***
	(0.0016)	(0.0063)	(0.0710)
IT Capital	0.0959***	0.1150***	0.1499***
	(0.0011)	(0.0037)	(0.0547)
# obs	654,100	613,857	183,495
Industry & Year FE	YES	YES	YES

Note: *** is significant at 1% level. Standard errors are clustered at the firm level. The number of observations for the CWDL estimation is substantially lower because it requires the first and second lag of investments in IT capital and non-IT capital while these are not required for the other estimators.

The output elasticity of IT capital is not significantly different between the manufacturing and services industries. The manufacturing industries have lower IT intensity than the services industries, as measured by the ratio of IT capital to value added. As a result, the marginal product of IT capital is higher for manufacturing industries, namely 1.58 in the manufacturing sector compared to 1.17 in the services sector. The marginal products of non-IT capital and labor are respectively 0.21 and 34,800 EUR for the manufacturing sector and 0.18 and 33,400 EUR for the services sector.[17] There are two possible explanations for such high marginal product of IT capital in the manufacturing industry: either user costs and adjustment costs from increasing IT capital are large such that firms retain from investing in IT capital, or there is a market failure that results in manufacturing firms underinvesting in IT capital. To gain deeper understanding in industry heterogeneity, we estimate the augmented production function at a more disaggregated level. Table 5 provides further details on differences in the output elasticity and the marginal product of IT capital across industries.

[17] For the manufacturing sector, $MP_{K^{IT}} = \frac{0.1144}{0.0723} = 1.58$; $MP_{K^{NIT}} = \frac{0.2176}{1.0300} = 0.21$; $MP_L = \frac{0.6640}{0.000019} = 34{,}769$ and for the services sector $MP_{K^{IT}} = \frac{0.1150}{0.0981} = 1.17$; $MP_{K^{NIT}} = \frac{0.1990}{1.1286} = 0.18$; $MP_L = \frac{0.6257}{0.0000187} = 33{,}431$. When computing MP_L with the wage bill input share, $MP_L = \frac{0.6640}{0.7025} = 0.95$ for manufacturing and $MP_L = \frac{0.6257}{0.6430} = 0.97$ for services.

TABLE 5: RESULTS PER INDUSTRY[18]

Industry (NACE codes)	Labor	Non-IT Capital	IT Capital	IT input share	Marginal Product IT
Agriculture, Forestry and Fishing (1-3)	0.43	0.42	0.05	0.03	1.84
High Tech Manufacturing (21; 26; 30)	0.75	0.16	0.13	0.08	1.67
Other Manufacturing (10-33 except Hightech)	0.65	0.23	0.11	0.07	1.51
Utilities (35-39)	0.53	0.30	0.13	0.03	3.61
Construction (41-43)	0.63	0.24	0.09	0.03	2.78
Wholesale and Retail (45-47)	0.61	0.19	0.13	0.09	1.45
Transportation and Storage (49-56)	0.64	0.23	0.06	0.04	1.51
Information and Communication (58-63)	0.65	0.17	0.19	0.27	0.68
Financial and Insurance (64-66)	0.68	0.17	0.11	0.14	0.76
Real Estate (68)	0.49	0.34	0.11	0.15	0.79
Professional, Scientific & Technical activities (69-75)	0.64	0.16	0.12	0.16	0.77
Administrative and Support activities (77-82)	0.67	0.22	0.11	0.12	0.87
Average	0.61	0.24	0.11	0.10	1.52

Note: The results in this table are from the ACF estimator. All regressions include industry and year fixed effects. Standard errors are clustered at the firm level. All estimates are significant at the 1% level. The number of observations for mining and quarrying firms is low, therefore these are omitted from the table.

Within the manufacturing sector, the output elasticity of IT capital is highest for high tech manufacturing industries, resulting in a higher marginal product of IT capital for high tech manufacturing industries than for the other manufacturing industries. Another interesting finding is that the marginal product of IT capital is relatively high for utilities and construction industries compared to the manufacturing and services industries.

For the services industries, the output elasticity of IT capital is highest for the Information and Communication industries. This is consistent with Bosworth and Triplett (2007), who show that productivity growth from IT capital within the services sector was highest for these industries. Yet, IT intensity is also highest in the information and communication industries, resulting in a marginal product of IT capital that is below the economy-wide average. Abstracting from potential discrepancies in adjustment costs across industries, creating output growth through investments in IT will be hardest in industries that have a relatively low marginal product of IT capital. This is so for all services industries, except for the wholesale and retail industries and transportation and storage industries. Together these industries account for 20% of employment and 25% of GDP. From a policy perspective, it would be interesting to stimulate IT investment in these industries since investing an additional euro in IT capital in these industries results in a gross rate of return of respectively 1.45 and 1.51 euro.

[18] The ranking of industries based on their marginal product of IT capital remains unchanged when constructing IT capital solely from IT goods. This result assures that differences in returns across industries are not caused by unobserved in-house IT service developments. One exception are the financial and insurance industries, in which the marginal product of IT capital increases substantially when IT services are not included. This is because in these industries IT services are a relatively large part of the IT capital stock.

4.3 Firm Heterogeneity

Most of the previous literature has focused on large firms, often using survey data, but it is unclear whether the earlier findings can be generalized for the population of small firms, who represent the bulk of the economy. Tambe and Hitt (2012) indicate this to be a major shortcoming in the literature. To the best of our knowledge, only Tambe and Hitt (2012), Hyatt and Nguyen (2010) and Bloom et al. (2010) investigated whether returns from IT are related with firm size. While Tambe and Hitt (2012) found that large firms benefit more from IT, Hyatt and Nguyen (2010) found the opposite while Bloom et al. (2010) did not find differences in returns from IT between small and large firms. However, the average number of employees in the study of Tambe and Hitt (2012) is more than 10,000 employees, while in Hyatt and Nguyen (2010) and Bloom et al. (2010) this is respectively 237 and 400 employees. As shown in figure A-2 of appendix A, our data set covers the firm size distribution more extensively. The mean and median employment in our data set is 15.7 and 3 employees, but our sample also contains very large firms with more than 10,000 employees. This allows us to more adequately test whether a size premium exists in returns on IT and fill this caveat in the literature. Table 6 divides the population of firms into seven bins according to firm size. For each bin, table 6 shows the results of a split sample estimation of the production function and the marginal product of IT capital.

TABLE 6: RESULTS FOR DIFFERENT SIZE BINS

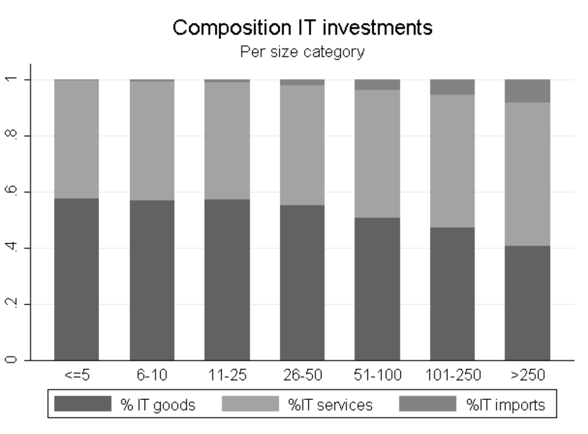
Firm size	# obs	Labor	Non-IT Capital	IT Capital	IT input share	Marginal Product IT
≤ 5 employees	511253	0.4824	0.2139	0.0799	0.0872	0.9157
6-10 employees	114654	0.7678	0.1514	0.0661	0.0568	1.1649
10-25 employees	100640	0.8071	0.1163	0.0842	0.0550	1.5315
26-50 employees	42124	0.8565	0.1065	0.1042	0.0556	1.8741
50-100 employees	16551	0.8163	0.0969	0.1157	0.0588	1.9658
100-250 employees	10728	0.8277	0.0934	0.1518	0.0644	2.3555
> 250 employees	6297	0.7308	0.1231	0.1663	0.0653	2.5473
Average		0.7555	0.1288	0.1097	0.0633	1.7650

Note: The results in this table are from the ACF estimator. All regressions include industry and year fixed effects. Standard errors are clustered at the firm level. All estimates are significant at the 1% level. As in section 4.1, the IT input share average is based on winsorized IT input shares at the 1% level to avoid outlier biases.

In section 4.1, which presents results for the entire population of firms, we found an average IT input share of 0.0808 and a marginal product of IT capital equal to 1.38. As is apparent from table 6, there is heterogeneity in firm size underlying these results. The IT input share reported in section 4.1 seems to be driven by the large tail of small firms in the population. For firms with less than five employees, the IT capital input share is on average 8.72% while for firms with more than five employees, the IT input share is between 5-6%. For firms with more than 5 employees, the IT input share remains fairly constant when firm size increases while the output elasticity rises. As a result, the marginal product of IT capital increases with firm size, in line with the findings of Tambe and Hitt (2012). This upward trend in the marginal product of IT capital also appears at more disaggregated levels of the firm size distribution, see figure A-3 in appendix. These findings support the hypothesis that large firms benefit more from IT investments.

An explanation for a size premium in returns from IT capital could be that large firms are more likely to provide IT services in-house instead of buying them externally. As such, the IT input share is underestimating the true IT intensity for large firms, leading to an upward bias in the marginal product estimate. However, this argument does not hold for the provision of IT goods as these are unlikely to be produced in-house. Figure 2 disentangles IT investments, which are at the basis of the IT capital stocks, for the different size groups.

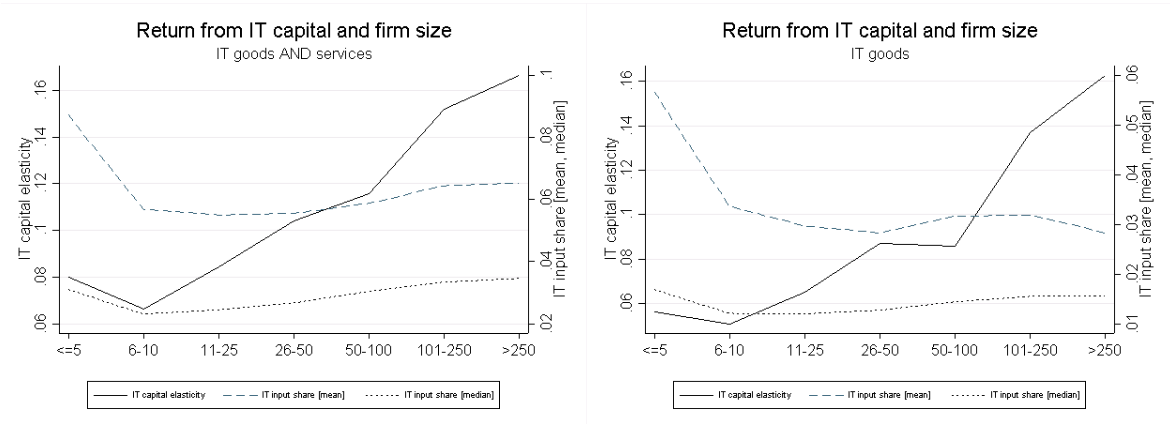
FIGURE 2: COMPOSITION IT INVESTMENTS AND FIRM SIZE



Note: This graph shows the average shares of IT goods, services and imports in total IT investments per size bin. Taking the median instead of the mean results in the same picture.

The share of IT goods in IT investments, and hence in IT capital, decreases with firm size, while the share of IT services and IT imports increase with firm size. This is not in line with the theory that IT services are produced more in-house in large firms leading to higher measured excess returns for large firms. When measuring excess returns using only IT goods to construct the capital stock we get a similar picture as before, cf. figure 3 which graphically shows the results from table 6 for IT capital constructed with respectively total IT investments and IT goods investments only. The size premium in returns from IT capital can thus not be explained by differences in the composition of IT capital.

FIGURE 3: RETURNS FROM IT CAPITAL AND FIRM SIZE



It could be that our IT capital coefficient is picking up complementary intangibles. As shown by Bloom et al. (2012, 2014), management practices are positively related to IT intensity and differences in returns from IT capital across firms can be attributed to a large extent to differences in management quality. As large firms are typically better managed (Bloom et al. 2007), differences in returns across the firm size distribution could be partly representing unmeasured management quality. If this is not controlled for, the average return from IT capital could be biased upwards and partly reflect this omitted variable. Although we use state of the art techniques to control for unobserved firm productivity in estimating the output elasticity of IT capital, these only control for management insofar it is comprised in firm productivity. To the extent that good management is costly, including wages as a control variable can help to proxy for omitted management quality, as in Broersma, McGuckin and Timmer (2003). Doing so does not change our findings on higher returns of IT capital for large firms. Under the assumption that management quality is fixed over time, a fixed effects model allows to validate the robustness of our results. Brynjolfsson et al. (1995) already indicated the importance of controlling for individual firm differences in the context of IT and productivity. They found that firm fixed effects account for up to half of the productivity benefits attributed to IT.[19] Table 7 shows the output elasticities of IT capital for each firm size bin, with firms with less than 5 employees as a reference category, with and without fixed effects.

TABLE 7: RESULTS FOR DIFFERENT SIZE BINS WITH FIXED EFFECTS

Value added production function	(1)	(2)	(3)	(4)
IT capital	0.0945*** (0.0009)	0.0772*** (0.0010)	0.0428*** (0.0009)	0.0362*** (0.0010)
IT capital * ≤ 5 employees		/		/
IT capital * 6-10 employees		-0.0009 (0.0017)		0.0009 (0.0013)
IT capital * 10-25 employees		0.0103*** (0.0021)		0.0073*** (0.0017)
IT capital * 26-50 employees		0.0177*** (0.0030)		0.0125*** (0.0025)
IT capital * 50-100 employees		0.0322*** (0.0046)		0.0214*** (0.0040)
IT capital * 100-250 employees		0.0515*** (0.0070)		0.0193*** (0.0060)
IT capital * > 250 employees		0.0838*** (0.0106)		0.0258*** (0.0113)
# observations	996,955	996,955	996,955	996,955
Firm fixed effects	NO	NO	YES	YES

Note: Standard errors are clustered at the firm level. *** is significant at the 1% level. Model (1) and (3) are the standard OLS production function with and without firm fixed effects. This models (2) and (4) are the same as the one used by Bloom et al. (2010) to infer whether there is a size premium in returns on IT capital: $y_{it} = \beta_l l_{it} + \beta_{IT} k_{it}^{IT} + \beta_{NIT} k_{it}^{NIT} + \beta^{Sj} s_{it}^{j} + \beta_{IT}^{Sj} \left(k_{it}^{IT} * s_{it}^{j}\right) + Z_{it} + \epsilon_{it}$ with s_{it}^{j} size bin dummies and Z_{it} the vector of year and industry controls. The table only shows β_{IT} and β_{IT}^{Sj} which measure respectively the effect of IT capital for firms with less than 5 employees and the additional effect according to the firm's size.

[19] Fixed effects control for any time fixed unobserved heterogeneity, which management can be argued to be, but also for returns from the part of the IT stock that is persistent over time. Therefore, fixed effects estimators are likely to underestimate the returns from IT capital.

Without accounting for firm fixed effects, we find the return from IT capital to be significantly higher for each size bin compared to the firm size bin just below. When accounting for firm fixed effects, we find that the trend in the size premium flattens out after the threshold of 100 full time equivalents is reached.[20] Since firm size and management scores are positively correlated (Bloom et al., 2007), the difference between the baseline OLS and firm fixed effects estimation suggests that our IT capital coefficient could indeed be reflecting unmeasured complementary assets, like management practices, to a certain extent. Nevertheless, the finding of a firm size premium in returns from IT capital is robust. In appendix D we move beyond split sample analyses and fully recognize firm heterogeneity by identifying firm specific output elasticities with a random coefficients production function. This approach also shows a positive relation between firm size and returns from IT capital.

4.4 IT and (aggregate) productivity growth

Early work in the literature on returns from IT capital was spurred by the famous quote of Robert Solow (1987) *"You can see the computer age everywhere but in the productivity statistics"*. This quote received much attention from academics because productivity growth indeed started to decline right at the moment computer investments took off. Houseman et al. (2015) showed that it is crucial to distinguish between IT producing and IT using industries. They found that productivity growth rates in the U.S. between 1997 and 2007 fall by almost half when computer producing industries are excluded. Also Acemoglu et al. (2014) found that IT producing industries drive the positive impact of IT investments on labor productivity. They conclude that the statement of IT to improve productivity in all industries may be exaggerated.

To gauge the impact from IT capital to aggregate GDP and aggregate productivity over the last decade, we use the Petrin and Levinsohn (2012, henceforth PL) decomposition and extend it by including IT capital and non-IT capital separately as production inputs. This decomposition allows us to shed light on the contribution of IT capital deepening to aggregate value added growth, which learns whether firms did or did not invest (enough) in IT capital. Furthermore, this decomposition contains a reallocation component for each production input. In a profit maximizing world, one would expect firms to reallocate resources towards its most profitable use. The reallocation components show the contribution to aggregate productivity growth from this mechanism. More specifically, it measures the contribution to productivity growth from reallocation of resources from low marginal value activities to high marginal value activities (relative to costs).[21] The IT capital reallocation component learns whether firms who should (not) invest in

[20] The firm fixed effects estimator identifies whether there is a difference between the size bins in how within firm variation in IT capital is related to within firm variation in output. Under the assumption that management quality in the firm is fixed over time, this robustness check shows that increasing IT capital increases output more in firms that are in the subgroups of large firms. However, the effect of within firm changes in IT capital with regard to output changes does not increase significantly anymore across subgroups with firms that have more than 100 employees.

[21] In a neoclassical setting without frictions, the value of the marginal product is equal to the marginal cost, leaving no room for improvements in aggregate productivity through reallocation of resources. In this scenario, the elasticity of output with respect to an input is equal to the share of expenditures for that input in total revenue. However, in a

IT, namely those with (low) high returns on IT capital, did (not) invest. Table 8 decomposes economy wide value added growth in labor deepening, non-IT capital deepening, IT capital deepening and productivity growth. Table 9 further decomposes aggregate productivity growth into (i) within firm technical efficiency growth, which shows whether firms become more productive on average, (ii) productivity growth through reallocation of resources from low to high marginal value activities and (iii) a residual fixed cost component. Productivity growth from reallocation is split up in productivity growth from labor reallocation, non-IT capital reallocation and IT capital reallocation.

TABLE 8: PL DECOMPOSITION I

In percentages	Aggregate Output growth	Contribution from labor growth	Contribution from non-IT capital growth	Contribution from IT capital growth	Contribution from productivity Growth
2004	5.89%	1.42%	1.09%	0.28%	3.10%
2005	4.64%	2.09%	0.85%	0.28%	1.41%
2006	4.34%	1.11%	0.33%	0.07%	2.83%
2007	5.48%	1.59%	0.76%	0.12%	3.02%
2008	0.02%	1.23%	0.81%	0.11%	-2.13%
2009	-3.04%	-1.53%	-0.07%	0.02%	-1.47%
2010	2.53%	-0.11%	-0.33%	-0.01%	2.98%
2011	3.68%	1.18%	0.11%	0.10%	2.29%
2012	-0.99%	-0.32%	-0.13%	-0.03%	-0.51%
2013	-0.60%	-1.10%	-0.80%	-0.09%	1.40%
Avg.	2.20%	0.56%	0.26%	0.08%	1.29%
St. Dev.	3.12%	1.23%	0.61%	0.12%	1.97%

Note: The decompositions are based on a subsample of firms for which all necessary variables are reported for all subsequent years the firm is in the sample. See table A-6 in appendix A for a comparison with other OECD countries.

On average, aggregate value added increased by 2.2% per year. What is apparent, is that this growth is largely driven by total factor productivity growth. The contribution of IT capital deepening to aggregate value added growth is only 0.08% on average. Especially after the great recession, there is no contribution to aggregate value added growth from IT capital deepening. This finding supports the idea that firms reduced investments after the great recession. Despite cheap capital, firms are cautious in their investment decisions. This is believed to be one of the reasons for the productivity puzzle of the last decade. Our results are in line with this idea, i.e. despite IT investments are interesting from a micro perspective, firms did not invest (enough) in IT capital with the result that there is no substantial contribution from IT to aggregate output growth.

world of imperfect competition, markups, taxes and adjustment costs drive a wedge between marginal products, which leads to a possible role for reallocation of resources in increasing aggregate productivity growth (Basu and Fernald, 2002).

TABLE 9: PL DECOMPOSITION II

In percentages	Aggregate productivity growth	Within firm productivity growth	Productivity growth through reallocation			Fixed cost
			Labor	Non-IT capital	IT capital	
2004	3.10%	0.13%	0.43%	0.51%	2.30%	-0.28%
2005	1.41%	-1.72%	0.52%	0.85%	1.59%	0.17%
2006	2.83%	0.60%	0.03%	0.72%	1.27%	0.21%
2007	3.02%	1.07%	0.09%	0.79%	1.00%	0.06%
2008	-2.13%	-3.15%	0.30%	0.22%	0.63%	-0.12%
2009	-1.47%	-1.69%	0.42%	-0.09%	0.16%	-0.28%
2010	2.98%	3.66%	-0.46%	-0.31%	0.05%	0.03%
2011	2.29%	1.42%	0.31%	-0.08%	0.37%	0.27%
2012	-0.51%	-0.97%	0.57%	-0.45%	0.18%	0.16%
2013	1.40%	1.11%	0.28%	-0.15%	-0.25%	0.41%
Avg.	1.29%	0.05%	0.25%	0.20%	0.73%	0.06%
St. Dev.	1.97%	1.97%	0.30%	0.48%	0.80%	0.23%

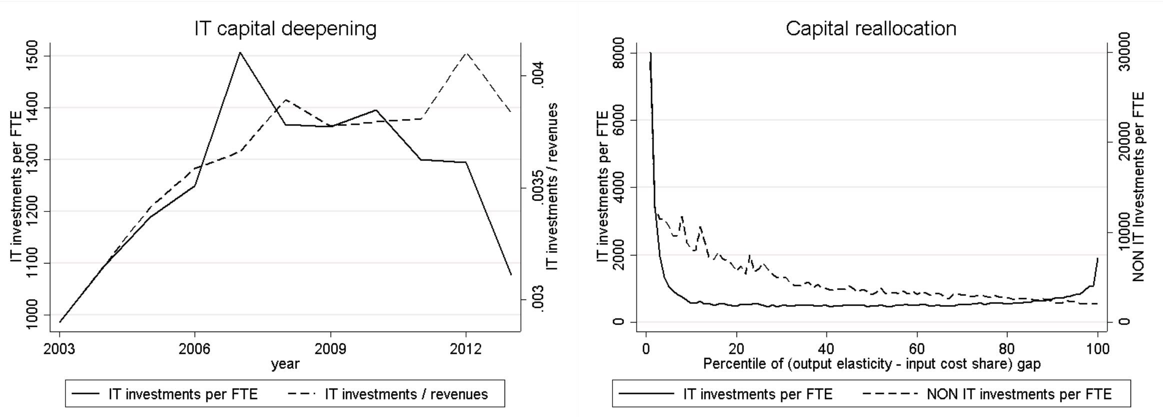
Note: The decompositions are based on a subsample of firms for which all necessary variables are reported for all subsequent years the firm is in the sample.

Consistent with earlier research on the Belgian economy, we find that the largest share of productivity growth is driven by reallocation of resources (Van den bosch and Vanormelingen, 2017). We find that IT capital reallocation, i.e. increases in IT capital in firms that have high benefits compared to costs from increasing IT capital, contributes on average 0.73% to aggregate productivity growth. As in our results on IT capital deepening, we find that this average is entirely driven by the pre-recession period. After the great recession, the contribution of IT capital reallocation, as well as non-IT capital reallocation, dropped substantially. These result indicate that in the post-recession period there was only a modest impact from IT capital reallocation to aggregate productivity growth, or in other words, our results suggest that firms with excess returns on IT capital invested too little in IT. Furthermore, the residual fixed cost term is relatively small in comparison to total reallocation, which indicates that reallocation of resources from low-value to high-value activities does a good job in explaining total reallocation.

Tables A-2 - A-5 in appendix A present the results of the PL decomposition for the subset of manufacturing and services industries separately. In line with our expectations for the Belgian economy, which is characterized by a decline in manufacturing and shift to services, we find that labor deepening is the most important determinant for aggregate output growth in services while having a negative impact on output growth in manufacturing. On the other hand, productivity growth is by far the most important factor for value added growth in the manufacturing sector, while it is not that important in the services sector. The contribution from IT capital deepening is low in both services and manufacturing industries, and in both sectors the post-recession slowdown in the contribution from IT and non-IT capital deepening clearly stands out. When taking a closer look at the determinants of aggregate productivity growth in manufacturing and services industries, we find that reallocation of resources explains about 60% of productivity growth in the manufacturing sector while it explains all of productivity growth in the services sector. Again we find for both sectors the same downward trend in the contribution of (non) IT capital reallocation to aggregate productivity over time.

To obtain additional insights in our results from the PL decomposition, figure 4 shows (i) in the left panel the evolution over time of the ratio of IT investments per employee and the share of IT investments in revenues and (ii) in the right panel the (non) IT investment intensity across the percentiles of the weighted output elasticity – input cost share distribution. The graph on capital reallocation indicates whether firms that have a large 'gap' between returns and costs from investing in (non) IT capital, and hence are in the upper percentiles of the 'gap' distribution, accordingly invest in (non) IT capital.

FIGURE 4: IT CAPITAL DEEPENING AND CAPITAL REALLOCATION



Note: The left panel shows yearly median real IT investments per employee and yearly real IT investments share in real revenues. All ratios are value added weighted. The right panel shows for each percentile of the distribution of the value added weighted gap between the output elasticity and the input cost share of (non) IT investments the value added weighted median next period (non) IT investment intensity, expressed as the ratio of real (non) IT investments per employee. Both the left and right panel show the same trends when including only manufacturing or only services firms.

The left panel shows that real IT investments per employee decreased after the great recession. The upward trend in the share of IT investments in revenues also stagnates after the great recession and is only around 0.3% of total revenues, which is still very low. This explains why the contribution of IT capital deepening is low in general and declines after the great recession. The right panel shows the IT investment intensity in function of the opportunities associated with IT investments, i.e. on the left are those firms for which the benefits from IT investments are low, and on the right are the firms for which benefits from IT investments are high. The figure shows a heavy left tail of observations for which the IT investment intensity is relatively high while the investment opportunity 'gap' for IT is low. The firms in this left tail are small, with on average 5 employees, and IT capital intensive with IT capital being on average 20% of the total capital stock while this is only 10% in the other firms. Apart from the left tail, IT investment intensity is relatively flat across the distribution. The same trend holds for non-IT investments. This is striking since one would expect that firms with large opportunities invest more. So there is a small group of firms that is IT intensive and persistently invests in IT while additional returns are rather low, while the majority of firms does not invest enough based on the difference between benefits and costs from IT investments. This misallocation of IT investments, together with our findings on low IT capital deepening, can reconcile the paradox of identifying returns from IT capital at the micro level, but not at the macro level.

Our findings of a low contribution from IT capital deepening to aggregate output and a high concentration of IT investments in a small group of firms is furthermore consistent with the empirical findings of declining business dynamism. Bijnens and Konings (2018) show that the decline in Belgian dynamism is highest for the most IT intensive industries.

5. IT and TFP dispersion

Our results show that the productivity returns to IT capital are positive and substantial for the average firm and we have shown that firm size matters for those returns. Another important question is whether IT can explain TFP differences across firms. Syverson (2004) showed that, even within narrowly defined sectors, productivity dispersion is large and Dunne, Foster, Haltiwanger and Troske (2004) found that computer investments are related to productivity dispersion across firms. We analyze to what extent this is also the case in our data.

To get a sense on how much of the variation in productivity IT explains, we investigate how much of the 90-10 TFP spread can be accounted for by IT investments per worker. We compare the explained spread in productivity from IT investments with the spread in productivity explained by human capital. We focus on these two determinants because they are prominent drivers of productivity dispersion amongst firms, see Syverson (2011). As we compared returns from IT capital in Belgium mostly with returns from IT capital in the United States throughout the paper, we continue to do so in this part of our analysis. To this end, we apply the same analysis as Bloom, Brynjolffson, Foster, Jarmin, Patnaik, Saporta-Eksten and Van Reenen (2017) and show their results next to ours.

TABLE 10: DRIVERS OF TFP DISPERSION

Dependent variable is demeaned TFP	Belgium			United States		
	(1)	(2)	(3)	(1)	(2)	(3)
IT investments per worker	0.0469*** (0.0010)		0.0406*** (0.0010)	0.015*** (0.003)		0.008*** (0.002)
Skills (share highly educated)		0.2086*** (0.0057)	0.1638*** (0.0058)		0.527*** (0.060)	0.126** (0.057)
Share of 90-10 explained	0.1016	0.0767	0.1482	0.0752	0.111	-
# firms	130,095	130,095	130,095	17,843	17,843	17,843

Note: *** is significant at 1% level. Standard errors are clustered at the firm level. The Belgian regressions are OLS regressions with as dependent NACE 4 industry demeaned TFP. IT investments per worker are equal to log(IT purchases / FTE employment) and skills is equal to the ratio of highly educated employees to total employees. The US regressions are OLS regressions with as dependent NAICS 6 industry demeaned TFP. IT investments are investments in computers per employee and skills are measured by the share of employees with a college degree. The 'share of 90-10 explained' is obtained by multiplying the regression coefficient of the variable of interest with the 90-10 distribution spread of this variable and dividing this by the 90-10 spread of the dependent (TFP). Specification (3) of the United States cannot be directly compared to its counterpart of Belgium since the United States analysis also includes management and R&D as drivers of TFP, which we have no data on.

IT investments per worker explain about 10% of the dispersion in productivity amongst firms, which is close to what Bloom et al. (2017) find for management. Human capital explains about 8% in productivity dispersion amongst firms, while it explains around 11% of TFP dispersion in the U.S. Together, IT and human capital explain about 15 percent of productivity dispersion in the Belgian economy.

Our results are close to those of Bloom et al. (2017), who find that the share of TFP dispersion that is explained by IT investments per worker is about 8%. An important difference is that the average firm size in the study of Bloom et al. (2017) is 167 employees, while in our sample this is only 18 employees. When we drop firms with less than 50 employees from our sample, the coefficient on IT investments per worker from model (3) remains stable at 0.0423 ($t = 11.49, p < 0.01$) while the coefficient on the skills variable increases from 0.2086 to 0.3957 ($t = 16.68, p < 0.01$). The share of the 90-10 spread in TFP explained by IT investments per employee remains similar at 0.1041 while the share of 90-10 spread in TFP explained by human capital increases from 0.0767 to 0.1743. Thus, human capital particularly explains TFP dispersion in large firms, while IT investments per employee explain TFP dispersion in both small and large firms. Altogether, IT investments per employee and human capital explain about 15 percent of TFP dispersion in the full sample and one fifth of the 90-10 spread in TFP in the subsample of firms with more than 50 employees. Given that 50% of firm-level TFP is measurement error (Collard-Wexler, 2011; Bloom, Floetotto, Jaimovich, Saporta-Eksten and Terry, 2012), these findings suggest that IT and human capital actually explains between 30 and 40 percent of total productivity dispersion in the Belgian economy.

6. Conclusion

Our society is increasingly transformed by IT, therefore it is important to understand the economic impact of IT. This paper provides new firm level evidence on returns from IT capital, which is possible by using a hitherto unexploited data set on IT purchases. More specifically, we merged data on IT expenditures with IT import data and annual accounts data, resulting in a sample of about 1,000,000 observations for the period 2002-2013. The data on IT expenditures covers both tangible and intangible IT purchases. This is a more comprehensive measure of IT capital than in earlier studies, which often relied on the number of computers per worker and hence exclude the intangible component of IT capital, e.g. Bloom et al. (2010). Another interesting feature of our data is that all firms with limited liability are included, so the data set contains both small and large firms, while earlier work was mostly, if not all, on large firms. We use the Perpetual Inventory Method to construct an IT capital stock and a non-IT capital stock for each firm. An augmented production function is estimated using state of the art techniques to avoid biases from unobserved heterogeneity in productivity. More specifically, we use the Ackerberg, Caves and Frazer (2015) and Collard-Wexler and De Loecker (2016) estimators to this end.

We find an output elasticity of IT capital around 0.10. This is higher than in earlier studies, where the output elasticity of IT capital was usually estimated around 0.05-0.06 (Cardona et al., 2013). The gap between the output elasticity of IT capital and its input share is substantial, and higher than for other production factors. This results in a higher marginal product for IT capital than for other production inputs, a finding that is consistent with earlier studies on IT capital. The novelty in our study, apart from how we construct the IT capital stock, is that we can determine the micro origins of these excess returns in terms of industry and firm heterogeneity. We show that both at the industry and firm level, there are differences in the output elasticity and marginal product of IT capital. We find that marginal product of IT capital is higher in manufacturing industries than in services industries, with the wholesale and retail industries and transportation and storage industries being notable exceptions. Next, we show there exists a size premium in returns on IT capital. To verify whether we not merely pick up complementary intangibles, we augment the model with controls for labor quality and estimate a firm fixed effects model, which controls for all unobserved complementary intangibles (e.g. management quality, Bloom et al. 2012) that could be picked up by the IT capital coefficient. The finding that large firms benefit more from IT appears to be robust.

Furthermore, we revisit the Solow paradox. Using the Petrin Levinsohn (2012) decomposition, we try to align earlier findings of excess returns from IT capital at the micro level with low returns from IT capital at the macro level. Our results indicate that this paradox can be explained by two causes: (i) too low IT investments and (ii) misallocation of IT investments. We find this effects to be particularly apparent after the great recession, which indicates that IT is a piece of the productivity puzzle of the last decade. Finally, we investigated to which extent IT can explain TFP dispersion across firms. We find that IT investments explain about one tenth of the dispersion in measured productivity.

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Appendix A: Additional tables and figures

TABLE A- 1: LITERATURE OVERVIEW OF STUDIES IN WHICH ELASTICITY OF IT CAPITAL IS ESTIMATED

Authors	Elasticity	Unit	Data		Region	N/year
			Start	End		
Our paper	+-0.10	Firm	2002	2013	Belgium	***90.000***
Van Reenen et al. (2010)	0.023	Firm	1998	2008	Europe	1900
Black and Lynch (2001)	0.05	Firm	1987	1993	U.S.	638
Black and Lynch (2004)	0.296	Firm	1993	1996	U.S.	284
Bresnahan et al. (2002)	0.035	Firm	1987	1994	U.S.	300
Brynjolfsson and Hitt (1995)	0.052	Firm	1988	1992	U.S.	n.a.
Brynjolfsson (1996)	0.044	Firm	1987	1991	U.S.	702
Brynjolfsson and Hitt (2003)	0.058	Firm	1987	1994	U.S.	1324
Dewan and Min (1997)	0.09	Firm	1988	1992	U.S.	773
Gilchrist et al. (2001)	0.021	Firm	1986	1993	U.S.	580
Brynjolfsson and Hitt (1996b)	0.048	Firm	1988	1992	U.S.	370
Lichtenberg (1995)	0.098	Firm	1988	1991	U.S.	1315
Tambe and Hitt (2012)	0.041	Firm	1987	2006	U.S.	1800
Bertschek and Kaiser (2004)	0.152	Firm	2000	2000	Europe	212
Bloom et al. (2010)	0.015	Firm	1995	2003	Europe	4809
Hempell et al. (2004)	0.041	Firm	1996	1998	Europe	972
Hempell (2005a)	0.06	Firm	1994	1999	Europe	1177
Mahr and Kretschmer (2010)	0.13	Firm	2000	2008	Europe	182
Hempell (2005b)	0.049	Firm	1994	1999	Europe	1222
Loveman (1994)	-0.06	Firm	1978	1984	Worldwide	60
Basant et al. (2006)	0.115	Firm	2003	2003	Asia	266
McGuckin and Stiroh (2002)	0.17	Industry	1980	1996	U.S.	10
Stiroh (2002a)	-0.071	Industry	1973	1999	U.S.	18
Acharya and Basu (2010)	0.031	Industry	1973	2004	Worldwide	384
O'Mahony and Vecchi (2005)	0.066	Industry	1976	2000	Worldwide	55
Venturini (2009)	0.138	Country	1980	2004	Europe	15
Dewan and Kraemer (2000)	-0.013	Country	1985	1993	Worldwide	36
Koutroumpis (2009)	0.012	Country	2002	2007	Worldwide	22
Madden and Savage (2000)	0.162	Country	1975	1990	Worldwide	43
Röller and Waverman (2001)	0.045	Country	1970	1990	Worldwide	21
Sridhar (2007)	0.15	Country	1990	2001	Worldwide	63

Source: Cardona et al. (2013)

Table A-2 shows the result of disentangling manufacturing wide value added growth into labor deepening, non-IT capital deepening, IT capital deepening and productivity growth.

TABLE A- 2: PL DECOMPOSITION I - ***MANUFACTURING INDUSTRIES***

In percentages	Aggregate output growth	Contribution from labor growth	Contribution from Non-IT capital growth	Contribution from IT capital growth	Contribution from productivity growth
2004	6.89%	0.51%	1.00%	0.26%	5.11%
2005	-0.66%	-0.14%	0.19%	0.24%	-0.95%
2006	3.38%	-0.56%	0.01%	0.02%	3.91%
2007	5.49%	0.05%	0.59%	0.04%	4.81%
2008	-1.46%	0.39%	0.52%	0.04%	-2.41%
2009	-7.94%	-2.55%	-0.29%	-0.07%	-5.03%
2010	4.79%	-1.63%	-0.35%	0.13%	6.64%
2011	1.06%	-0.75%	-0.15%	0.03%	1.93%
2012	0.26%	-1.71%	-0.14%	-0.08%	2.19%
2013	0.44%	-1.64%	-0.73%	-0.05%	2.86%
Avg.	1.23%	-0.80%	0.07%	0.06%	1.91%
St. Dev.	4.27%	1.04%	0.52%	0.12%	3.67%

Note: The decompositions are based on a subsample of manufacturing firms for which all necessary variables are reported for all subsequent years the firm is in the sample.

Table A-3 shows the result of further decomposing aggregate manufacturing productivity growth into within firm productivity growth, productivity growth through reallocation of resources from low to high marginal value activities and a residual fixed cost component. Productivity growth from reallocation is split up in productivity growth from labor reallocation, non-IT capital reallocation and IT capital reallocation.

TABLE A- 3: PL DECOMPOSITION II - ***MANUFACTURING INDUSTRIES***

In percentages	Aggregate productivity growth	Within firm productivity growth	Productivity growth through reallocation			Fixed cost
			Labor	Non-IT capital	IT capital	
2004	5.11%	2.32%	0.46%	0.44%	1.96%	-0.06%
2005	-0.95%	-3.06%	0.08%	0.66%	1.19%	0.18%
2006	3.91%	1.92%	0.41%	0.30%	1.02%	0.26%
2007	4.81%	3.86%	-0.09%	0.32%	0.68%	0.05%
2008	-2.41%	-3.62%	0.36%	0.53%	0.44%	-0.13%
2009	-5.03%	-4.62%	0.45%	-0.25%	-0.08%	-0.52%
2010	6.64%	6.15%	0.80%	-0.22%	0.02%	-0.11%
2011	1.93%	0.69%	0.66%	-0.05%	0.25%	0.39%
2012	2.19%	0.97%	1.13%	-0.56%	0.23%	0.42%
2013	2.86%	1.98%	0.75%	-0.26%	-0.26%	0.66%
Avg.	1.91%	0.66%	0.50%	0.09%	0.54%	0.11%
St. Dev.	3.67%	3.44%	0.35%	0.41%	0.68%	0.34%

Note: The decompositions are based on a subsample of manufacturing firms for which all necessary variables are reported for all subsequent years the firm is in the sample.

Table A-4 shows the result of disentangling the services sector value added growth into labor deepening, non-IT capital deepening, IT capital deepening and productivity growth.

TABLE A-4: PL DECOMPOSITION I - **SERVICES INDUSTRIES**

In percentages	Aggregate output growth	Contribution from labor growth	Contribution from Non-IT capital growth	Contribution from IT capital growth	Contribution from productivity Growth
2004	4.55%	2.79%	1.74%	0.38%	-0.36%
2005	7.33%	3.53%	1.35%	0.39%	2.06%
2006	4.40%	1.96%	0.42%	0.07%	1.95%
2007	7.86%	2.60%	0.94%	0.18%	4.13%
2008	2.53%	2.15%	0.89%	0.17%	-0.68%
2009	-2.15%	-0.88%	-0.28%	0.06%	-1.06%
2010	0.84%	0.48%	-0.44%	-0.11%	0.91%
2011	3.47%	2.49%	0.20%	0.16%	0.63%
2012	-2.03%	0.38%	-0.01%	-0.03%	-2.38%
2013	-3.81%	-1.11%	-0.88%	-0.18%	-1.65%
Avg.	2.30%	1.44%	0.39%	0.11%	0.36%
St. Dev.	4.02%	1.61%	0.83%	0.19%	1.98%

Note: The decompositions are based on a subsample of services firms for which all necessary variables are reported for all subsequent years the firm is in the sample.

Table A-5 shows the result of further decomposing aggregate productivity growth in the services industries into within firm productivity growth, productivity growth through reallocation of resources from low to high marginal value activities and a residual fixed cost component. Productivity growth from reallocation is split up in productivity growth from labor reallocation, non-IT capital reallocation and IT capital reallocation.

TABLE A-5: PL DECOMPOSITION II - **SERVICES INDUSTRIES**

In percentages	Aggregate productivity growth	Within firm productivity growth	Productivity growth through reallocation			Fixed cost
			Labor	Non-IT capital	IT capital	
2004	-0.36%	-3.72%	0.51%	0.22%	2.66%	-0.04%
2005	2.06%	-2.32%	1.30%	0.77%	1.85%	0.46%
2006	1.95%	0.10%	-0.22%	0.70%	1.37%	0.01%
2007	4.13%	1.50%	0.31%	0.67%	1.27%	0.38%
2008	-0.68%	-2.39%	0.31%	0.27%	0.81%	0.32%
2009	-1.06%	-1.71%	0.28%	0.24%	0.34%	-0.20%
2010	0.91%	2.72%	-1.64%	-0.37%	0.09%	0.11%
2011	0.63%	0.10%	0.08%	0.02%	0.46%	-0.03%
2012	-2.38%	-2.64%	0.21%	-0.33%	0.22%	0.16%
2013	-1.65%	-0.72%	-0.17%	-0.07%	-0.26%	-0.42%
Avg.	0.36%	-0.91%	0.10%	0.21%	0.88%	0.08%
St. Dev.	1.98%	2.02%	0.74%	0.41%	0.90%	0.27%

Note: The decompositions are based on a subsample of services firms for which all necessary variables are reported for all subsequent years the firm is in the sample.

TABLE A- 6: OECD GROWTH ACCOUNTING 1995-2014

	GDP growth	**Labor deepening**	**ICT capital deepening**	**Non ICT capital deepening**	**Multifactor productivity growth**
Italy	0.43	0.12	0.21	0.34	-0.24
Japan	0.78	-0.47	0.34	0.28	0.63
Portugal	1.08	-0.09	0.32	0.70	0.18
Denmark	1.23	0.29	0.39	0.42	0.13
Germany	1.26	0.02	0.25	0.22	0.78
France	1.54	0.22	0.28	0.39	0.65
Belgium	**1.75**	**0.57**	**0.37**	**0.43**	**0.37**
Austria	1.78	0.32	0.33	0.45	0.69
Netherlands	1.83	0.57	0.36	0.44	0.48
Switzerland	1.90	0.50	0.45	0.48	0.47
Spain	1.97	1.05	0.25	0.84	-0.14
United Kingdom	2.08	0.59	0.28	0.38	0.84
Finland	2.11	0.46	0.21	0.30	1.17
Sweden	2.30	0.44	0.50	0.43	0.94
United States	2.35	0.46	0.44	0.42	1.03
Canada	2.50	0.97	0.35	0.50	0.69
New Zealand	2.56	1.28	0.57	0.53	0.17
Australia	3.20	1.07	0.47	0.84	0.81
Korea	4.26	-0.03	0.29	1.21	2.79
Ireland	4.44	1.15	0.28	1.01	2.03

Source: OECD Compendium of Productivity Indicators 2016

Our results from the PL decomposition on average GDP growth and the contribution from labor deepening to aggregate GDP growth are in line with the results for Belgium reported by the OECD. We find a larger share of multifactor productivity growth and a lower contribution from capital deepening than the OECD. Our findings are closer to those of Van Beveren and Vanormelingen (2014). It is possible that our results deviate because the OECD averages also contain the years 1995-2003, which we have no information on. As our results also indicate, capital deepening decreased over time in the Belgian economy, so this could explain the difference in the decomposition components.

FIGURE A- 1: SCATTER PLOT VALUE ADDED AND IT CAPITAL

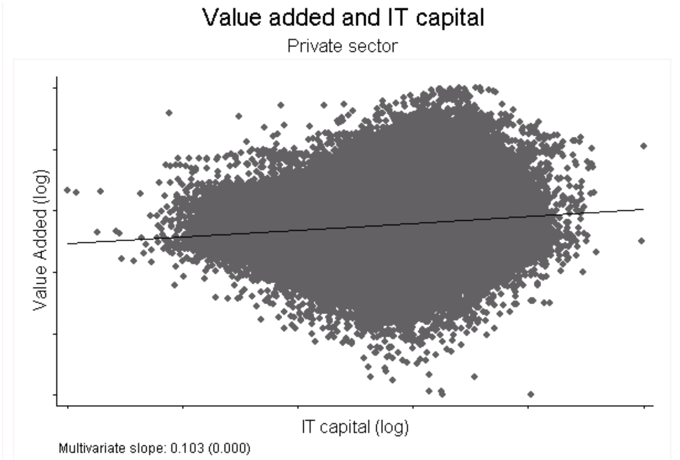
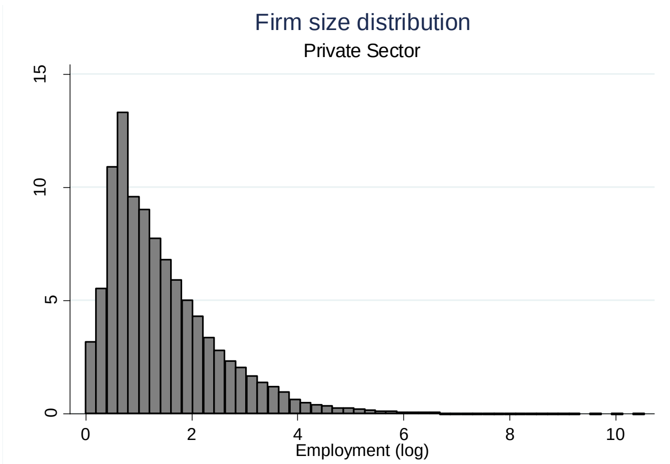


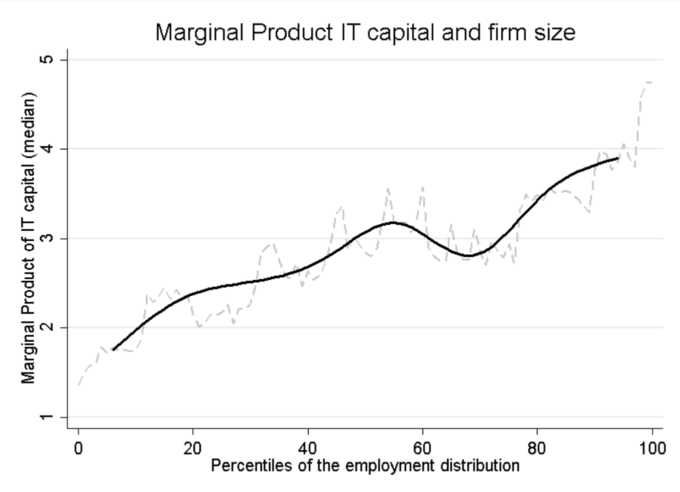
Figure A-1 shows the positive relation between value added and IT capital after removing variation in value added from non-IT capital, labor and industry- and time-fixed effects for the entire private sector. The graph shows a positive association between IT capital and added value, with a slope coefficient around 0.10. It is also apparent that there is a lot of heterogeneity underlying this effect, this is discussed in the sections on industry and firm heterogeneity.

FIGURE A- 2: FIRM SIZE DISTRIBUTION OF THE SAMPLE



Note: Histogram of firm size, measured in full time equivalents, of all firms in private sector for which we can obtain IT capital. Employment figures from the social balance sheets only include those who are in the personnel register of the firm.

FIGURE A- 3: MARGINAL PRODUCT OF IT CAPITAL ACROSS FIRM SIZE DISTRIBUTION



Note: As in the main body, the IT input share average is based on winsorized IT input shares at the 1% level to avoid outlier biases.

Table 6 shows that the marginal product of IT capital increases with firm size based on a split sample analysis. However, these results might still obfuscate heterogeneity in the relation between the marginal product of IT capital and firm size within a size bin. Therefore, figure A-3 shows the relation between the marginal product of IT capital and firm size at a more disaggregate level. The graph shows the median of the firm level marginal products of IT capital for each percentile of the firm size distribution. Not surprisingly, the positive relation between firm size and returns from IT investments appears again. Furthermore, this upward trend is robust to taking industry heterogeneity in output coefficients into account by estimating the production function for each size bin in each industry separately and deriving the marginal products from these estimates.

Appendix B: Data

B 1. IT purchases and VAT data

We use VAT listings, yearly customer filings and import data at the product-firm level to construct non-IT and IT capital stocks at the firm level. Each firm with limited liability is obliged to report to the federal public service of finance all its purchases and sales for tax purposes. These listings are a rich source of information, from which we can deduce how much non-IT and IT investments firms make. This will in turn allow us to construct non-IT and IT capital stocks (see section B2.).

On their VAT declaration, firms have to specify how much assets they bought in Belgium or abroad. This is a direct measure for the total investment of a firm. Combining this information with the IT investments of the firm allows to obtain non-IT investments. IT investments are obtained from the VAT customer listings firms have to hand in each year. In this listing, firms have to report the VAT number and total sales of each customer.[22] Of course, this also learns how much the customers bought. We exploit this information to obtain IT purchases for each customer. More specifically, we use the customer listings of firms that are active in NACE codes of IT goods and IT services industries (see appendix E). From their customer listings, we deduce how much IT goods and IT services each of its customers bought. For each customer, we sum its IT purchases over all IT producing firms.[23] This sum is our firm level measure for Belgian IT investments. We add to this the IT purchases from abroad, which we retrieve from the customs for imports coming outside the EU and the intrastat trade survey for imports to Belgium coming from within the EU, to obtain the IT investments of the firm. By deducting IT investments from total investments, we retrieve non-IT investments of the firm.

Figure A-3 shows IT intensity, approximated by the ratio of real IT capital to total revenue, in the various 2-digit NACE manufacturing sectors in Belgium and figure A-4 plots the same for the service sectors. We aggregated the average firm level real IT capital, real non-IT capital and real sales up to the level of the 2-digit NACE sectors they belong to and took the ratio of the aggregate real IT capital stock to aggregate real sales. Note that IT producing sectors have a relatively higher IT intensity than other sectors. Other sectors in manufacturing that are intensive users are Manufacturing of Printing and Manufacturing of Other Transport Equipment. IT intensity in services is on average higher than in manufacturing. Particularly Real Estate and computer and telecom related services have high IT intensities.

[22] Natural persons are excluded. The customer listing serves taxation purposes, hence firms only have to report customers in this listing that are also subject to the VAT system, so basically all firms with limited liability. Information on self-employed are not considered in this paper.

[23] We exclude IT producing industries (see appendix E). For firms that are active in these industries, IT purchases could have the purpose of reselling, rather than investment or consumption.

FIGURE A- 4: IT INTENSITY IN MANUFACTURING INDUSTRIES

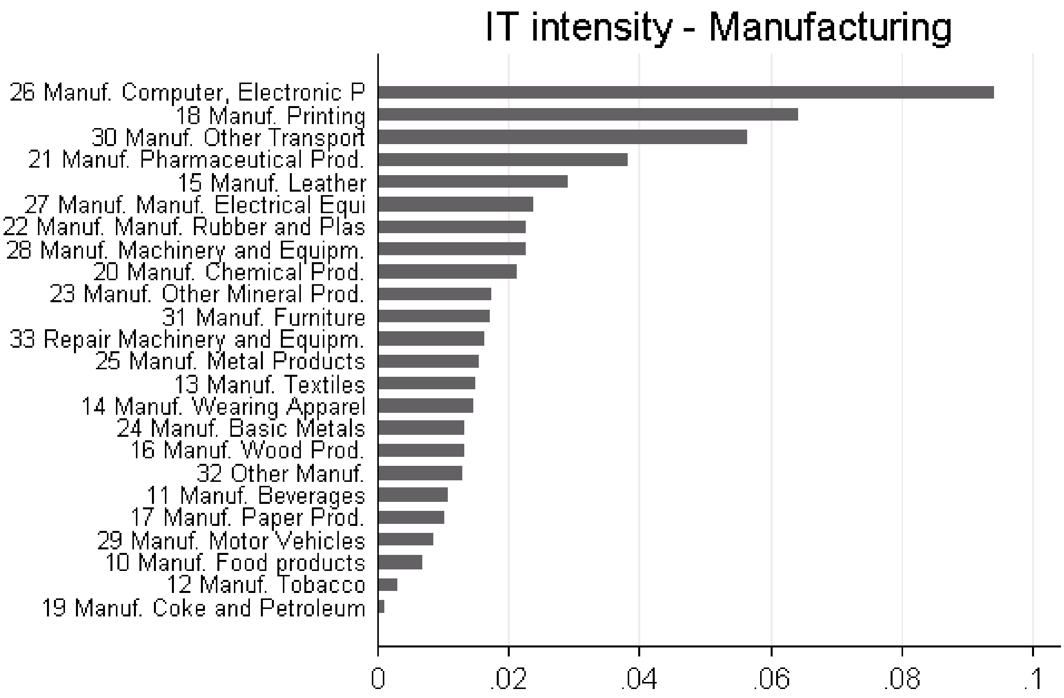
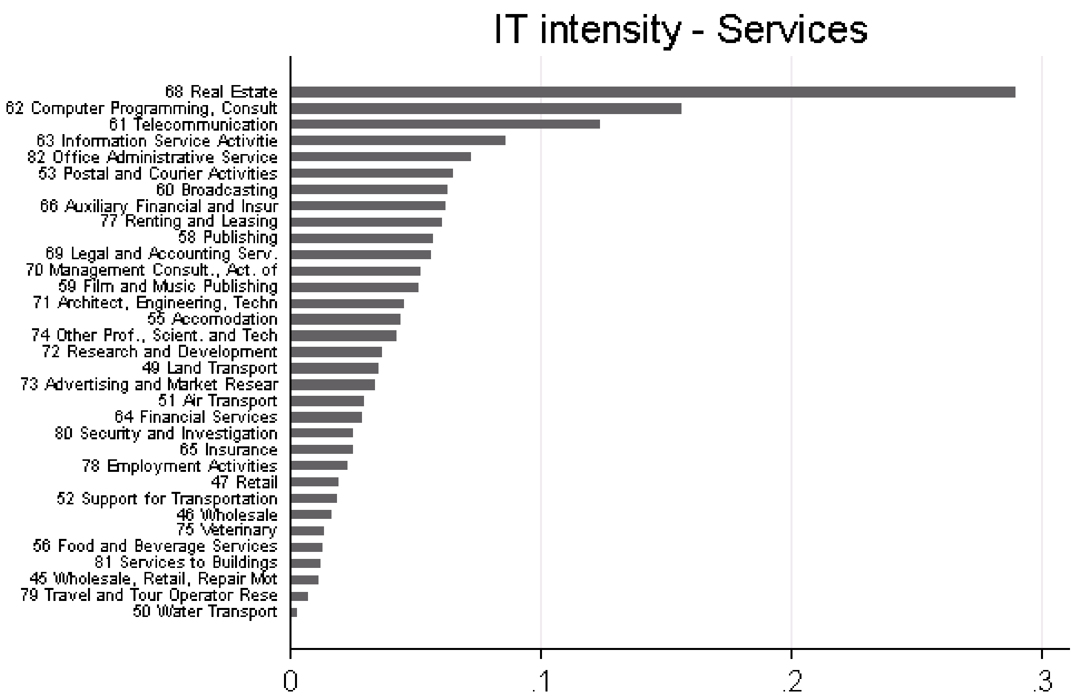


FIGURE A- 5: IT INTENSITY IN SERVICES INDUSTRIES



B 2. Construction capital stocks

We construct real IT capital and real non-IT capital stocks using the Perpetual Inventory Method (PIM). This method allows us to optimally exploit our unique data on IT purchases and total investments. The formula of the PIM is the following:

$$\widetilde{K}_{it}^{(N)IT} = \widetilde{K}_{it-1}^{(N)IT} * \left(1 - \delta^{(N)IT}\right) + \tilde{I}_{it}^{(N)IT} \quad (1)$$

In which $\widetilde{K}_{it}^{(N)IT}$ refers to the real (non) IT capital stock of firm i in year t, $\delta^{(N)IT}$ refers to the depreciation rate for (non) IT capital and $\tilde{I}_{it}^{(N)IT}$ refers to real (non) IT investments. We rely on data of the EU KLEMS initiative to turn the nominal values from our data set into real values.[24] The EU KLEMS data provides gross fixed capital formation deflators at the 2 two-digit level for the entire period of our sample. For non-IT investments, we use the average of the gross fixed capital formation deflator from The Netherlands, France and Luxembourg. For IT investments, we first compute 'computing equipment' and 'computer software and databases' deflators based on the average of these deflators from The Netherlands, France and Luxembourg. We take the average of these 'computing equipment' and 'computer software and databases' deflators as our IT deflator. The EU KLEMS data also contains information on depreciation rates for both IT and non-IT capital. The yearly depreciation rate for IT capital is fixed to 31.5 percent, consistent with IT capital depreciation rates in other research. For non-IT capital we assume a fixed depreciation rate of 15 percent.[25] The results are robust to deviations from these depreciation rates.

The first step in applying the PIM is calculating the initial IT and non-IT capital stocks. This is necessary because IT capital is part of total tangible fixed assets but not reported separately in annual accounts.[26] The literature does not provide a straightforward solution to obtain initial capital stocks. In this appendix, we describe the approach used to obtain the results from the main body of the paper. In table A-12 - A-16 of appendix C, we show that our results are robust to alternative ways of obtaining the (initial) capital stocks. To obtain the initial stocks, we predicted the firm's IT capital intensity and use this to split initial nominal total tangible fixed assets into initial nominal non-IT capital and initial nominal IT capital. We use our unique data on IT purchases and investments to predict this IT capital intensity. First, we obtain nominal IT and non-IT investments from:

$I_{it}^{IT} = IT\ purchases_{it}$ (see appendix E for which purchases are classified as IT)
$I_{it}^{NIT} = Investments_{it} - I_{it}^{IT}$ (2)

We use the aforementioned gross fixed capital formation and IT deflator to turn these nominal investments into real values. Next, we take the average of the real investment flows from the first 3 years the firm is in the sample. We do this because firms do not invest in IT every year and to avoid errors in the initial capital stocks from outlier investments. We limit ourselves to the first 3 years because (i) longer periods could be less informative about the initial IT capital stock (ii) firms can change their business model over time, i.e. becoming more or less IT focused (iii) this is consistent with the finding that it takes some years before intangible stocks reach steady state in most industries (Knott et al., 2003).

We then use this average real (non) IT investment of the first 3 years to simulate what the real (non) IT capital stock would be under the assumption that this investment is representative for the stock. Following Hall and Mairesse (1995) and Hempell (2002) in earlier work on using the PIM to construct R&D and IT capital stocks:

[24] More specifically, we rely on the capital input files from The Netherlands, France and Luxembourg of the September 2017 release. There is no capital input file for Belgium so we assume that the average of prices for IT in The Netherlands, France and Luxembourg are close to those of Belgium.
[25] Production function estimates are similar using lower depreciation rates for non-IT capital in the range of 8-10%.
[26] We refer to the European System of Accounts for further information.

$$\widetilde{K}_{i1}^{(N)IT} = \widetilde{I}_{i0}^{(N)IT} + \left(1 - \delta^{(N)IT}\right)\widetilde{I}_{i-1}^{(N)IT} + \left(1 - \delta^{(N)IT}\right)^2 \widetilde{I}_{i-2}^{(N)IT} + \cdots = \frac{\widetilde{I}_{i1}^{(N)IT}}{g_{it}^{(N)IT} + \delta^{(N)IT}} \tag{3}$$

With $\widetilde{I}_{i1}^{(N)IT}$ the real (non) IT investment of the firm in the first year, $g_{it}^{(N)IT}$ the constant average past growth rate of real (non) IT investments and $\delta^{(N)IT}$ the (non) IT capital depreciation rate. Under the assumption that the average real (non) IT investment of the first 3 years is representative for the investment strategy, we can then predict IT capital intensity as follows:[27]

$$IT\ capital\ intensity_i = \widetilde{K}_{i1}^{IT} / \left[\widetilde{K}_{i1}^{IT} + \widetilde{K}_{i1}^{NIT}\right] = \frac{\widetilde{I}_{i1}^{IT}}{\delta^{IT}} / \left[\frac{\widetilde{I}_{i1}^{IT}}{\delta^{IT}} + \frac{\widetilde{I}_{i1}^{NIT}}{\delta^{NIT}}\right] \tag{4}$$

This firm-level IT capital intensity measure is by construction between 0 and 1. We use this ratio to split initial nominal total tangible fixed assets into initial nominal non-IT capital and initial nominal IT capital:

$$\begin{aligned} K_{i0}^{IT} &= IT\ capital\ intensity_i * TFA_{i0} \\ K_{i0}^{NIT} &= TFA_{i0} - K_{i0}^{IT} \end{aligned} \tag{5}$$

The aforementioned IT deflator and gross fixed capital formation deflators are then used to turn these nominal initial stocks into real initial stocks. After obtaining the initial capital stocks from equation (5) and investments from equation (2) and deflating them with the deflators we constructed from EU KLEMS, equation (1) learns how to obtain real (non) IT capital stocks at the firm level.

There are observations for which reported IT purchases are larger than reported total investments. For such observations, we set non-IT investments equal to zero. Given the novelty of our data, we investigated how this could potentially affect our analysis to guarantee that our estimates are not biased. Reporting higher IT purchases than investments can occur for several reasons:

1) *Firms make mistakes in filling in the VAT declarations.* We checked the accounting regulations with accountants and auditors. They ensured that each purchase of IT equipment should be registered as an investment. Nevertheless, they admit that firms sometimes make mistakes against this rule. Such mistakes could be seen as idiosyncratic errors and are not problematic for our analyses.
2) *Firms make mistakes on purpose in filling in the VAT declarations.* Although IT equipment should be registered as an investment by law, reporting IT purchases as intermediate inputs when profits are high could be interesting. This way, profits are lower and taxes are minimized. Since our productivity measures are TFPR measures, they contain demand shocks, and hence partly reflect profitability. If this mechanism would be at play, IT investments and hence the IT capital stock would be underestimated for firms with high value added. This would result in an underestimation of the correlation between value added and IT capital and hence a downward bias of the output elasticity of IT capital. The output elasticity on IT capital would then be a lower bound estimate of the true output elasticity.
3) *IT purchases are IT consumables, like cartridges and printing paper, rather than IT equipment.* Such expenditures are reported as material costs instead of investments. The legal guideline on small IT consumables that cost less than 1000euro, is to report these as material inputs. However, each purchase from an IT producer larger than 250euro is included in our IT purchases variable. Since not all IT purchases are IT investments, our IT investments measure is probably overestimated. As a rough robustness check, we assumed 25% of IT purchases to be IT consumables rather than IT equipment, this did not affect our estimates.
4) *IT purchases are made in firms that are not active in the selected IT goods and IT services industries.* When firms purchase IT equipment from suppliers that are not active in the NACE codes which we selected as IT equipment producers, e.g. when firms buy IT equipment in supermarkets, this purchase is not

[27] The EU KLEMS contains IT capital stocks for France, Luxembourg and The Netherlands. We used these to obtain proxies for $g_{it}^{(N)IT}$ at the 2digit level. Including these in equation (4) does not affect the results.

accounted for in our IT investment measure. This would imply that our IT investment measure is underestimated. The potential bias this would induce in our results works in the opposite direction as the potential concern raised about IT purchases being consumables instead of investments. However, we believe that, in practice, the amount of IT purchases that are either IT consumables or made in firms that are not active in the selected NACE codes is rather small and therefore not problematic.

5) *IT expenditures are effectively intermediate inputs instead of IT investments.* Some industries can have a production process in which IT purchases serve as inputs. This could for example explain why IT purchases are higher than investments for 70% of observations in NACE 2680 (Manufacture of magnetic and optical media). Leaving out a set of industries, based on the ratio of observations for which IT purchases exceed investments, does not alter our findings. We also tried to exploit the time dimension in our data to investigate whether IT purchases end up in materials rather than in investments. More specifically, we estimated the following model:

$$\Delta m_{it} = \beta_0 + \beta_1 \Delta inv_{it}^{NIT} + \beta_2 \Delta sales_{it} + \beta_3 k_{it} + \beta_4 l_{it} + \beta_{5-510} \Delta purch_{it}^{IT} * Ind_{4digit} + \varepsilon_{it}$$

This model allows to investigate for which four digit industries changes in IT expenditures are correlated with changes in material expenditures. The model includes changes in gross output and changes in non-IT investments to control for increases in material expenditures from increasing demand or non-IT investments. Labor and capital are included to control for firm size. The purpose of this model is not to causally infer which industries have a production process in which IT products are used as intermediate input. However, this simple model can help to check whether there is systematically more correlation between IT expenditures and material expenditures in some industries. The results indicate that changes in material expenditures are mostly explained by changes in gross output. The coefficient of IT purchases growth is neither higher nor more often significant for those industries in which there is a high percentage of observations that report higher IT purchases than investments. These results support our assumption that IT expenditures are not systematically reported as material input.

As final robustness check for the aforementioned potential issues, we did our analyses again after dropping all observations for which IT purchases were larger than reported investments.

TABLE A- 7: REDUCED SAMPLE (NACE 1-82)

Value Added	OLS		ACF	
Production Function	All observations	Reduced sample	All observations	Reduced sample
Labor	0.6783***	0.6418***	0.6289***	0.5938***
	(0.0015)	(0.0015)	(0.0022)	(0.0043)
Non-IT Capital	0.1853***	0.2557***	0.2109***	0.3157***
	(0.0013)	(0.0016)	(0.0019)	(0.0085)
IT Capital	0.0945***	0.0640***	0.1115***	0.0677***
	(0.0009)	(0.0009)	(0.0014)	(0.0009)
# obs	996,955	740,880	839,946	590,226
Industry & Year FE	YES	YES	YES	YES

*** is significant at 1% level. Standard errors are clustered at the firm level.

Dropping observations for which IT expenditures are larger than reported investments increases the non-IT capital coefficient and lowers the IT capital coefficient. This is hardly surprising since the highly IT intensive firms are not included anymore and the production function reflects the importance of IT capital in the production process. The qualitative findings regarding returns from IT capital hold.

Appendix C: Robustness checks

All empirical research comes with assumptions and choices on the most appropriate model. The results in the main body are based on timing assumptions that are standard in the literature. This section shows results for alternative data generating processes and different timing assumptions on the capital stocks.

C.1 Alternative Data Generating Processes

In the paper, the same data generating process as in Olley and Pakes (1996) is assumed: firms choose how much IT investments they make in year *t* and these investments become part of the productive capital stock in year *t+1*. This way, there is no simultaneity between current productivity and IT capital, i.e. IT capital is chosen before current productivity was observed by the firm, and since current productivity is controlled for by the control function approach, the identification of the IT capital coefficient is unbiased.

C.1.1 IT investments become productive immediately

Identification problems arise when IT investments become productive immediately. In the main body of the paper, we follow the standard assumption of the productivity literature that it takes one period to install capital. Investments I_t that are observed in the law of motion for capital, $K_t = K_{t-1} * (1-\delta) + I_t$, are decided upon in $t-1$ but only installed and paid in year t. Under the alternative data generating process that IT investments become productive in the same year as they are ordered, I_t is decided upon, installed and paid in year t. This conveys an identification problem since the decision on I_t is now correlated with ξ_{it} in equation (3), i.e. the decision on how much IT capital to employ in the production process in year t is correlated with the productivity shock the firm observes in year t. This discussion is similar to the arguments that Bond and Söderbom (2005) and ACF (2015) raise about the choice of labor. To solve for this potential simultaneity bias, the same way forward as with the labor variable can be applied, i.e. instrument IT capital with its lagged value. Table A-8 shows the results from this modeling approach with the ACF estimator.

TABLE A- 8: IT INVESTMENTS BECOME PRODUCTIVE IMMEDIATELY

Value Added Production Function	ACF (1)	ACF (2)
Labor	0.6289*** (0.0022)	0.6283*** (0.0026)
Non-IT Capital	0.2109*** (0.0019)	0.1199*** (0.0011)
IT Capital	0.1115*** (0.0014)	0.1455*** (0.0036)
# obs	839,946	800,215
Industry & Year FE	YES	YES

Note: *** is significant at 1% level. Standard errors are clustered at the firm level.

Model (1) is the baseline model, in model (2) we instrument IT capital with its lagged value. The results show that the IT capital coefficient does increase significantly. Hence, the results in the paper serve as a lower bound for the scenario in which IT investments become productive in the same period as they were purchased.

C.1.2 Learning from IT investments

In the main body of the paper, we neglect the potential impact of IT investments on the evolution of productivity. Equation (3) explicitly states $\omega_{it} = g(\omega_{it-1}) + \xi_{it}$, so productivity is modeled as if it evolves according to an exogenous process. However, when firms invest in IT in year t, this may affect the firm's expectations about productivity in year $t + 1$. Cassiman and Vanormelingen (2013), Doraszelski and Jaumandreu (2013) and De Loecker (2013) show the importance of controlling for learning from innovation, R&D and export when estimating production functions. We extend our model in a similar way as these authors to allow the firm's expectations on future performance (productivity) to be affected by current IT investments. We do this by modifying the second stage of the ACF estimation procedure such that the evolution of productivity explicitly includes IT investments: $\omega_{it} = g(\omega_{it-1}) + \text{Inv}_{t-1}^{\text{IT}} + \xi_{it}$. Table A-9 shows the results from modeling IT investments in the law of motion in three different ways.

TABLE A- 9: LEARNING FROM IT INVESTMENTS

Value Added Production Function	ACF (1)	ACF (2)	ACF (3)	ACF (4)
Labor	0.6289***	0.6231***	0.6254***	0.5963***
	(0.0022)	(0.0036)	(0.0038)	(0.0047)
Non-IT Capital	0.2109***	0.2194***	0.2473***	0.2040***
	(0.0019)	(0.0065)	(0.0062)	(0.0071)
IT Capital	0.1115***	0.0909***	0.0918***	0.0898***
	(0.0014)	(0.0039)	(0.0028)	(0.0149)
# obs	839,946	804,715	867,878	573,857
Industry & Year FE	YES	YES	YES	YES

Note: *** is significant at 1% level. Standard errors are clustered at the firm level.

Model (1) is the baseline model without allowing for learning from IT investments. Model (2) includes a dummy in the law of motion that indicates whether or not a firm invested in IT in year $t - 1$. Model (3) includes IT investment intensity of year $t - 1$ in the law of motion and model (4) includes lagged IT investments directly in the law of motion. Under learning from past IT investments, we expect the IT capital coefficient to be biased upwards since too much variation in output (controlling for the other production inputs) will be attributed to variation in IT capital when the learning mechanism is not modeled. We find that the IT capital coefficient is indeed lower in specifications (2), (3) and (4) which allow for learning from past IT investments experience. However, the differences are not to the extent that they invalidate the conclusions we drew in the paper from our point estimates.

C.1.3 Results from restricted sample

TABLE A- 10: COMPARING OLS, ACF AND CWDL ON RESTRICTED SAMPLE

Value Added Production Function	OLS	OLS Restricted sample	ACF	ACF Restricted sample	CWDL	CWDL Restricted sample
Labor	0.6783***	0.6138***	0.6289***	0.5518***	0.4923****	0.4917***
	(0.0015)	(0.0027)	(0.0022)	(0.0105)	(0.0061)	(0.0071)
Non-IT Capital	0.1853***	0.2831***	0.2109***	0.3119***	0.3911***	0.5025***
	(0.0013)	(0.0026)	(0.0019)	(0.0183)	(0.0611)	(0.0581)
IT Capital	0.0945***	0.1279***	0.1115***	0.1322***	0.1213***	0.1213***
	(0.0009)	(0.0020)	(0.0014)	(0.0065)	(0.0426)	(0.0353)
# obs	996,955	221,707	839,946	221,707	330,567	221,707
Industry & Year FE	YES	YES	YES	YES	YES	YES

Note: *** is significant at 1% level. Standard errors are clustered at the firm level.

The IT capital coefficient is lowest with the OLS estimator and not statistically different between the ACF and CWDL estimator both for the full sample and the restricted sample. Also, the labor coefficient is highest with OLS and lowest with CWDL in both the full and the restricted sample. Finally, the non-IT capital coefficient is highest with CWDL and lowest with OLS for both sample sizes.

C.2 Alternative ways to construct IT capital

C.2.1: Including communication goods in IT capital

In the data section we show that communication goods are only a small part of the ICT investments of a firm. Table A-11 shows the results when including communication goods such that we obtain an ICT capital stock.

TABLE A- 11: RESULTS ICT CAPITAL

Value Added Production Function	OLS		ACF		CWDL	
	IT	ICT	IT	ICT	IT	ICT
Labor	0.6783***	0.6780***	0.6289***	0.6265***	0.4923****	0.4850***
	(0.0015)	(0.0014)	(0.0022)	(0.0035)	(0.0061)	(0.0058)
Non-IT Capital	0.1853***	0.1853***	0.2109***	0.2110***	0.3911***	0.3912***
	(0.0013)	(0.0013)	(0.0019)	(0.0050)	(0.0611)	(0.0636)
IT Capital	0.0945***	0.0963***	0.1115***	0.1192***	0.1213***	0.1444***
	(0.0009)	(0.0009)	(0.0014)	(0.0027)	(0.0426)	(0.0426)
# obs	996,955	1,036,401	839,946	959,757	330,567	351,257
Industry & Year FE	YES	YES	YES	YES	YES	YES

Note: *** is significant at 1% level. Standard errors are clustered at the firm level. The number of observations for the CWDL estimation is substantially lower because it requires the first and second lag of investments in IT capital and non-IT capital while these are not required for the other estimators.

The output elasticity of ICT capital is very close to the output elasticity of IT capital, hence all our findings can be generalized for ICT capital.

C.2.2: Calculating initial capital stocks from more aggregated IT intensity measures

Instead of using firm level IT intensity measures, this robustness check shows the results when the initial IT capital stock is derived from more aggregated IT intensity measures. More specifically, we derive the initial capital stock from aggregate investment ratios at the two- and four-digit level instead of at the firm level.

TABLE A- 12: INITIAL CAPITAL STOCKS FROM AGGREGATED IT INTENSITY

Value Added	OLS			ACF		
Production Function	(1)	(2)	(3)	(1)	(2)	(3)
Labor	0.6783***	0.7127***	0.7119***	0.6289***	0.6397***	0.6417***
	(0.0015)	(0.0013)	(0.0013)	(0.0022)	(0.0031)	(0.0030)
Non-IT Capital	0.1853***	0.1720***	0.1681***	0.2109***	0.2207***	0.2172***
	(0.0013)	(0.0012)	(0.0012)	(0.0019)	(0.0055)	(0.0055)
IT Capital	0.0945***	0.0636***	0.0658***	0.1115***	0.0805***	0.0790***
	(0.0009)	(0.0008)	(0.0008)	(0.0014)	(0.0013)	(0.0012)
# obs	996,955	1,303,429	1,303,269	839,946	1,133,509	1,133,410
Industry & Year FE	YES	YES	YES	YES	YES	YES

Note: *** is significant at 1% level. Standard errors are clustered at the firm level. Model (1) is the baseline model from the paper. Models (2) and (3) are the alternative specifications of the robustness check.

This robustness check shows that our results are robust to reducing cross sectional heterogeneity by calculating the initial capital stocks from more aggregate IT intensity measures.

C.2.3: IT capital calculated from IT intensity instead of the PIM approach

The results in the main body of the paper and in other robustness checks applies the PIM method to obtain either IT capital, non-IT capital or both. The PIM approach is standard in the productivity literature. However, as discussed in appendix B, there is some noise on the IT investments variable. We argued in appendix B that there is no pattern in this noise. Yet, any noise in the investment variables could be exacerbated by the PIM approach. Therefore, the following robustness check does not make use of the PIM method. Instead, IT capital is obtained by multiplying a firm's average IT intensity with its total tangible fixed assets.[28] Non-IT capital is obtained by subtracting IT capital from total tangible fixed assets, as in Brynjolfsson and Hitt (1996) and Dedrick, Kraemer and Shih (2013).

TABLE A- 13: IT CAPITAL CALCULATED FROM IT INTENSITY

Value Added	OLS		ACF	
Production Function	(1)	(2)	(1)	(2)
Labor	0.6783***	0.7427***	0.6289***	0.7071***
	(0.0015)	(0.0013)	(0.0022)	(0.0019)
Non-IT Capital	0.1853***	0.1274***	0.2109***	0.0914***
	(0.0013)	(0.0013)	(0.0019)	(0.0025)
IT Capital	0.0945***	0.0559***	0.1115***	0.0656***
	(0.0009)	(0.0010)	(0.0014)	(0.0015)
# obs	996,955	1,122,172	839,946	1,038,336
Industry & Year FE	YES	YES	YES	YES

Note: *** is significant at 1% level. Standard errors are clustered at the firm level. Model (1) is the baseline model from the paper. Model (2) is the alternative specification of the robustness check. We do not include the CWDL results since this approach explicitly relies on investments as instruments for the capital stocks. Because of the way the capital stocks are computed in this robustness check, using investments as instruments for the capital stocks is invalid.

Both the IT and non-IT capital coefficients are lower in model (2), which is unsurprising given that this approach ignores the time series variation in the capital stocks originating from investments. Therefore we interpret these coefficient estimates as an absolute lower bound.

[28] The average IT intensity of a firm over the entire sample period is used since contemporaneous IT intensity could still be subject to outliers in IT investments.

C.2.4: Only IT capital with PIM approach

In the paper, both IT capital and non-IT capital are obtained from using the PIM. In doing so, non-IT investments are obtained by subtracting IT purchases from total investments. As detailed in appendix B, there could be mismeasurement in IT purchases. If this would be the case, then this mismeasurement affects both the IT and non-IT capital stocks through errors in the investment flows. Therefore, this robustness check relies on data from the annual accounts for the non-IT capital stock. The IT capital stock is calculated with the PIM, and non-IT capital as the residual of the book value of total tangible fixed assets, as in robustness check C.2.3.

TABLE A- 14: IT CAPITAL WITH PIM & NON-IT CAPITAL AS RESIDUAL OF TANGIBLE FIXED ASSETS BOOK VALUE

Value Added Production Function	OLS		ACF		CWDL	
	(1)	(2)	(1)	(2)	(1)	(2)
Labor	0.6783***	0.6865***	0.6289***	0.6571***	0.4923****	0.4742***
	(0.0015)	(0.0014)	(0.0022)	(0.0031)	(0.0061)	(0.0058)
Non-IT Capital	0.1853***	0.1656***	0.2109***	0.1304***	0.3911***	0.1873***
	(0.0013)	(0.0009)	(0.0019)	(0.0028)	(0.0611)	(0.0233)
IT Capital	0.0945***	0.0806***	0.1115***	0.1096***	0.1213***	0.1550***
	(0.0009)	(0.0008)	(0.0014)	(0.0028)	(0.0426)	(0.0453)
# obs	996,955	949,081	839,946	850,875	330,567	322,832
Industry & Year FE	YES	YES	YES	YES	YES	YES

Note: *** is significant at 1% level. Standard errors are clustered at the firm level. Model (1) is the baseline model from the paper. Model (2) is the alternative specification of the robustness check. The number of observations for the CWDL estimation is substantially lower because it requires the first and second lag of investments in IT capital and non-IT capital while these are not required for the other estimators.

The estimates, and hence qualitative findings derived in the paper, from the IT capital coefficients are robust. The non-IT capital coefficients are now lower, which can be explained by modeling it as a residual from tangible fixed assets, so not taking into account variation from non-IT investments.

C.2.5: IT capital stock on PIM and non-IT capital stock based on book value

In all specifications, the non-IT capital stock is basically a residual. This is so because non-IT capital is (i) obtained from the PIM based on non-IT investments that are calculated by subtracting IT purchases from total investments or (ii) obtained from subtracting the IT capital stock from the book value of tangible fixed assets (C.2.4). This implies that any mismeasurement in IT investment or misspecification in the construction of the IT capital stock will show up in the non-IT capital stock as well. Therefore, this robustness check shows the results for calculating the IT capital stock with the PIM method while using the reported book value of total tangible fixed assets as non-IT capital stock.

TABLE A- 15: IT CAPITAL WITH PIM & NON-IT CAPITAL AS TOTAL TANGIBLE FIXED ASSETS BOOK VALUE

Value Added Production Function	OLS		ACF		CWDL	
	(1)	(2)	(1)	(2)	(1)	(2)
Labor	0.6783***	0.6982***	0.6289***	0.6694***	0.4923****	0.4782***
	(0.0015)	(0.0014)	(0.0022)	(0.0031)	(0.0061)	(0.0057)
Non-IT Capital	0.1853***	0.1731***	0.2109***	0.1469***	0.3911***	0.2038***
	(0.0013)	(0.0010)	(0.0019)	(0.0028)	(0.0611)	(0.0263)
IT Capital	0.0945***	0.0695***	0.1115***	0.0927***	0.1213***	0.1138**
	(0.0009)	(0.0008)	(0.0014)	(0.0025)	(0.0426)	(0.0458)
# obs	996,955	1,033,019	839,946	955,964	330,567	330,022
Industry & Year FE	YES	YES	YES	YES	YES	YES

Note: *** is significant at 1% level. ** is significant at 5% level. Standard errors are clustered at the firm level. Model (1) is the baseline model from the paper. Model (2) is the alternative specification of the robustness check. The number of observations for the CWDL estimation is substantially lower because it requires the first and second lag of investments in IT capital and non-IT capital while these are not required for the other estimators.

Since the non-IT capital stock now also contains IT capital, both the coefficients for non-IT capital and IT capital should be lower. This is exactly what this robustness check shows.

C.2.6: Non depreciating IT capital

An argument often made when estimating the returns from IT capital is that IT investments only contribute to output with a lagged effect. A survey on managers suggested it takes up to five years before IT investments pay off (Brynjolfsson, 1993). Another study of Brynjolfsson, Malone, Gurbaxani and Kambil (1994) found that it took two to three years before organizational impacts of IT are felt. In our main specification, we apply an annual geometric depreciation rate of 31.5%. Although it is common in the literature to do so, this approach may induce a discrepancy between capital productivity and capital wealth (Harper, 1982).[29] In this study, we are interested the productive IT capital rather than the market value of IT capital. Under lagged returns from IT capital, the true current productive IT capital stock is underestimated in the way we model it, which then would potentially result in a biased estimate of the IT output elasticity. For robustness, we show the estimates for non-depreciating IT capital, which is the most extreme solution to cope with the argument that the productive IT capital stock does not depreciate as fast as its market value.

TABLE A- 16: NON DEPRECIATING IT CAPITAL

Value Added Production Function	OLS		ACF		CWDL	
	(1)	(2)	(1)	(2)	(1)	(2)
Labor	0.6783***	0.6798***	0.6289***	0.6127***	0.4923****	0.4869***
	(0.0015)	(0.0015)	(0.0022)	(0.0040)	(0.0061)	(0.0059)
Non-IT Capital	0.1853***	0.1855***	0.2109***	0.2012***	0.3911***	0.3062***
	(0.0013)	(0.0013)	(0.0019)	(0.0048)	(0.0611)	(0.0562)
IT Capital	0.0945***	0.0921***	0.1115***	0.1655***	0.1213***	0.3896***
	(0.0009)	(0.0009)	(0.0014)	(0.0038)	(0.0426)	(0.0447)
# obs	996,955	996,955	839,946	924,544	330,567	330,567
Industry & Year FE	YES	YES	YES	YES	YES	YES

Note: *** is significant at 1% level. Standard errors are clustered at the firm level. Model (1) is the baseline model from the paper. Model (2) is the alternative specification of the robustness check. The number of observations for the CWDL estimation is substantially lower because it requires the first and second lag of investments in IT capital and non-IT capital while these are not required for the other estimators.

Since IT capital is now assumed not to depreciate over time, the importance of IT capital in the production process is now likely to be overestimated, which is what the results suggest. Whereas we interpret the results in robustness check C.2.3 as an absolute lower bound, we interpret these results as an absolute upper bound of the returns from IT capital.

[29] The assumption of geometric depreciation avoids the distinction between productive capital and capital wealth. Productive capital reflects the efficiency of capital, which is in theory the marginal rate of technical substitution between old capital and new capital. Capital wealth reflects the market value of capital, which is obtained by depreciating the capital stock to account for changes in the real prices of the assets. Assuming that the efficiency of IT capital declines geometrically over time by the IT capital depreciation rate is not consistent with the finding of lagged returns from IT capital.

Appendix D: Extensions

D.1. Firm size heterogeneity: Random Coefficients production function

We split our sample in bins to investigate the heterogeneity in the return from IT capital for small and large firms. Although dividing the sample into bins of different firm sizes is intuitively appealing, from an econometric perspective this can be argued to be a rather arbitrary approach. Therefore, we augment our analyses with a random coefficients model in which we estimate firm specific output elasticities (Swamy, 1970). The random coefficient model fully recognizes firm heterogeneity and exploits the panel structure to obtain a firm specific output elasticity for IT capital on top of an output elasticity that represents an average effect for the entire sample. Alcácer et al. (2013) illustrate the potential of random coefficient models in strategic management research and Kasahara, Schrimpf and Suzuki (2017) show how random coefficient production functions can prove to be usefulness in the industrial organization literature by allowing for production functions that are heterogeneous across firms beyond Hicks-neutral technology. We follow Knott (2008) in how to specify the random coefficient model:

$$y_{it} = (\beta_0 + \beta_{0,i}) + (\beta_l + \beta_{l,i})l_{it} + (\beta_{IT} + \beta_{IT,i})k_{it}^{IT} + (\beta_{NIT} + \beta_{NIT,i})k_{it}^{NIT} + \epsilon_{it}$$

In which the coefficients with index *i* refer to the firm specific output elasticities and the coefficients without this index to the average output elasticity.[30]

TABLE A- 17: RANDOM COEFFICIENTS PRODUCTION FUNCTION (NACE 1-82)

Value Added Production Function	Fixed coefficient	Firm specific coefficient		
		P10	P90	Std. Dev.
Labor	0.5506*** (0.0012)	-0.2231	0.1910	0.1871
Non-IT Capital	0.1385*** (0.0008)	0.0000	0.0000	0.0000
IT Capital	0.0530*** (0.0006)	-0.0066	0.0059	0.0060
# obs	1,089,042			
Industry & Year FE	YES	YES	YES	YES

*** is significant at 1% level.

Although the focus of this paper is on IT capital, it is worth noting that there is large firm level heterogeneity on the labor coefficient and no firm level heterogeneity on the non-IT capital coefficient. In figures A-5 and A-6 we show the relation between the IT capital output elasticities and firm size. For the sake of interest, we also show heterogeneity in the IT capital output elasticities in function of firm age in figure A-7. Scatter plot A-5 shows that the output elasticity of IT capital increases with firm size. Box plot A-6 shows that the median IT elasticity increases while its variance decreases for firms with up to 50 employees, after which this trend reverses, except for the firms with more than 250 employees. The median IT elasticity furthermore increases with firm age, while the variance in IT elasticities decreases with firm age.

[30] Note that, just as with OLS, we ignore potential endogeneity issues in this specification. Kasahara et al. (2017) propose a way forward on this by extending the Gandhi, Navarro, Rivers (2013) framework. As the random coefficient model only serves as robustness check, we retain from these more advanced approaches.

FIGURE A- 6: SCATTERPLOT FIRM SPECIFIC IT CAPITAL COEFFICIENTS AND FIRM SIZE

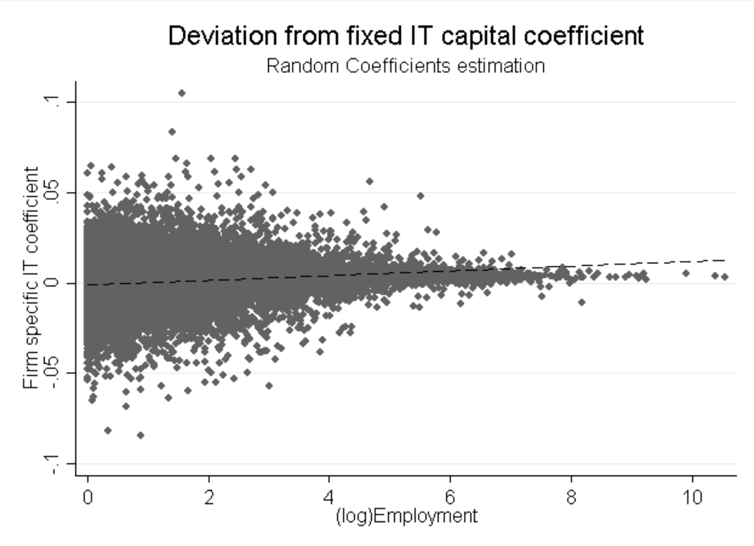


FIGURE A- 7: BOXPLOTS FIRM SPECIFIC IT CAPITAL COEFFICIENTS AND FIRM SIZE

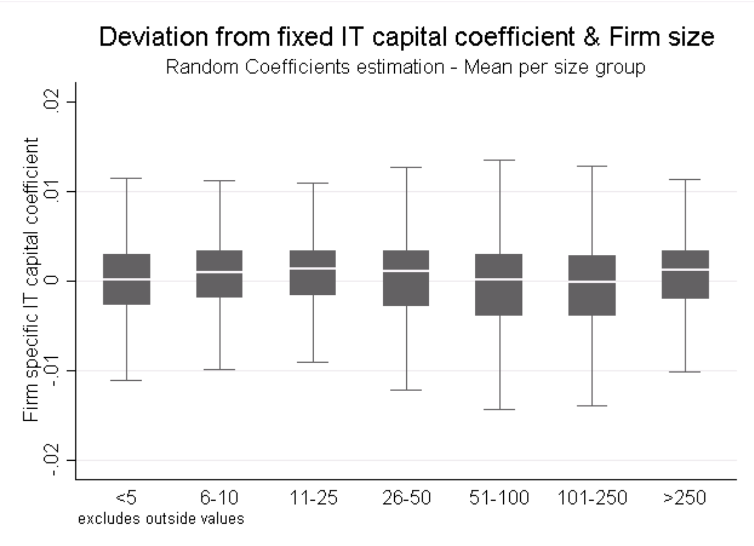
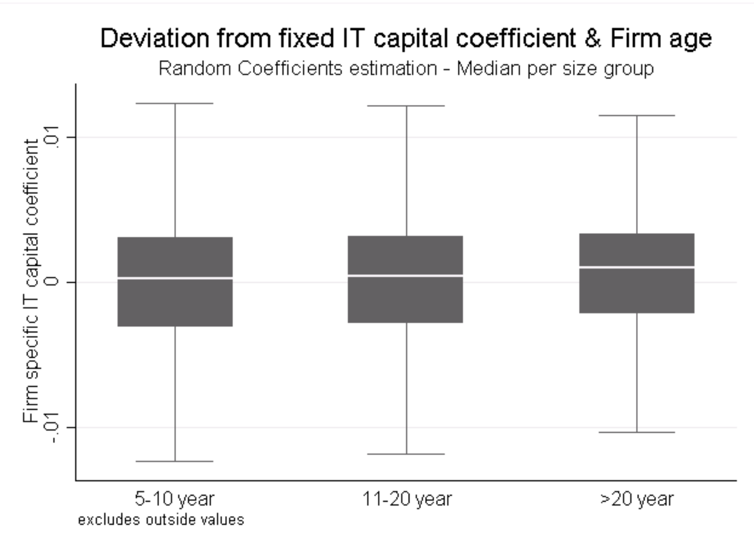


FIGURE A- 8: BOXPLOTS FIRM SPECIFIC IT CAPITAL COEFFICIENTS AND FIRM AGE



Appendix E: Definitions

To obtain IT investments, we use VAT listings of firms that produce IT equipment. Earlier studies used very aggregate (mostly two-digit, sometimes three-digit) definitions of IT producing industries.[31] Data at such aggregate levels comprises more than IT production only. For example, Houseman et al. (2015) and Acemoglu et al. (2014) use data from the NAICS 334 industry, which also includes manufacturing of audio and video equipment; navigational, measuring, electromedical, and control instruments; and magnetic and optical media. The reason they select this industry is because the BEA does not publish more disaggregate data. Having firm level data allows for a more narrow classification of I(C)T producing industries. Firms that are active in the NACE four-digit codes below, are considered to be producing I(C)T equipment.

TABLE A- 18: IT CAPITAL COMPOSITION

IT goods	
NACE-code	Description
2620	Manufacture of computers and peripheral equipment
4651	Wholesale of computers, computer peripheral equipment and software
4741	Retail sale of computers, peripheral units and software in specialized stores
5829	Other software publishing
IT services	
NACE-code	Description
6200	Computer programming, consultancy and related activities
6201	Computer programming activities
6202	Computer consultancy activities
6203	Computer facilities management activities
6209	Other information technology and computer service activities
6311	Data processing, hosting and related activities
6312	Web portals
Imports IT goods	
NACE-code	Description
2620	Manufacture of computers and peripheral equipment
5829	Other software publishing

TABLE A- 19: COMMUNICATIONS CAPITAL COMPOSITION

Communication goods	
NACE-code	Description
2630	Manufacture of communication equipment
4652	Wholesale of electronic and telecommunications equipment and parts
4742	Retail sale of telecommunications equipment in specialized stores
Communication services	
NACE-code	Description
6110	Wired telecommunications activities
6120	Wireless telecommunications activities
6130	Satellite telecommunications activities
6190	Other telecommunications activities
Imports communication goods	
NACE-code	Description
2630	Manufacture of communication equipment

[31] Examples are Bloom, Draca, Kretschmer, Sadun and Van Reenen (2010), Houseman, Bartik & Sturgeon (2015), Acemoglu, Autor and Dorn (2014), Stiroh (2002) and Van Ark, Melka, Mulder, Timmer and Ypma (2002).

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RLP Brussels – Company's number: 0203.201.340
Registered office: boulevard de Berlaimont 14 – BE-1000 Brussels
www.nbb.be

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Layout: Analysis and Research Group
Cover: NBB AG – Prepress & Image

Published in October 2018