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Abstract

ICT-intensive firms are often found to have a better performance than their non-ICT-intensive counterparts. Along with investing in ICT capital they have to adapt their production and business processes in order to reap the potentials implied by the use of ICT. Are these firms also more resilient in times of crisis? We study this question by exploiting a novel and unique data set from the Micro-Moments Database. Covering 12 countries, 7 industries and the period from 2001 to 2010, the data allow us to distinguish between ICT-intensive and non-ICT-intensive firms within industries. We find evidence that indeed during the crisis in 2008 and 2009, ICT-intensive firms were hit less hard with respect to their productivity. This holds in particular for firms from service industries. Moreover, ICT-intensive firms were also more successful in introducing process innovations during that period which could explain their better productivity performance compared to non-ICT intensive firms.

JEL Classification: H12; J24; O31; O47.

Keywords: ICT; innovation; productivity; economic crisis; resilience; meso-level data.

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1 Introduction

During an economic crisis the process of creative destruction is reinforced which comes with huge economic and social costs such as firm exits, unemployment and lower productivity. To reduce these costs it is important to understand what makes firms, industries and countries more resilient. ICT, as a general purpose technology, may be one potential source of firms' resilience. Firms using ICT in a clever way may be able to deal with economic shocks more flexibly through easier reorganisation of their production processes, and possibly can achieve a higher competitiveness, while firms lagging in the adoption of new technology face the risk of being driven out of the market. ICT and its inherent innovative capabilities may thus increase the resilience in economic downturns.

Are ICT-intensive firms, compared to non-ICT-intensive firms, more resilient in times of crisis? We study the comparative performance of ICT-intensive firms in terms of their productivity and innovation success exploiting a novel and unique dataset. The Micro Moments Database (MMD) comprises information at the meso-level for 12 countries and 7 industries. This dataset allows us going beyond the traditional growth accounting setting where industries – rather than firms – are classified according to their intensity of ICT usage. Instead, the MMD focuses more on the firm level and on heterogeneity within industries, allowing to study more detailed aggregates by firm-characteristics such as ICT-intensity. Applying a difference-in-difference framework, we find evidence that ICT-intensive firms, especially from service industries, indeed were hit less hard by the economic crisis. Their productivity level and growth hardly decreased during the period 2008 to 2009 whereas non-ICT-intensive firms experienced a strong reduction in productivity. Also, ICT-intensive firms became relatively more innovative in terms of realizing process innovations. This latter finding fits to the hypothesis that ICT allow firms to adjust their production processes in times of crisis and in that way allow them to cope better with the increased competitive pressure during an economic crisis. Our results are robust with respect to the inclusion of different control variables, the use of various estimation samples and alternative ways of measuring the crisis.

Our contribution is twofold: Firstly, we provide first evidence on the role of ICT for the

resilience of firms and countries in times of an economic crisis. Such knowledge is important for economic policy that is in search for strategies to improve resilience towards potential future crisis. Secondly, we contribute to the broader literature on ICT and productivity by illustrating the benefits of micro-aggregated industry data, which so far has not been used to study the ICT-productivity relationship.

2 Literature

The link between productivity and ICT has been studied extensively at the macro level (e.g. Jorgenson and Stiroh, 1999; Stiroh, 2002; van Ark et al., 2008; Jorgenson and Timmer, 2011), as well as at the micro level (see the surveys by Draca et al., 2007; Bertschek, 2012; Cardona et al., 2013). The measured size of the contributions of ICT to productivity seems to depend on the available data and on the methodology used. In particular, the evidence on excess returns to ICT compared to other capital is mixed (Draca et al, 2007; O'Mahony and Vecchi, 2005). Moreover, there are different routes how ICT may affect firm performance. An important link between ICT and productivity is innovation. As so-called general purpose technologies (Bresnahan and Trajtenberg, 1995), ICT diffuse throughout the whole economy and enable innovation in adopting firms and sectors (see for example Brynjolfsson and Saunders, 2010, Brynjolfsson and McAfee, 2011) leading to higher productivity. Hall et al. (2013), for example, consider investment in ICT and in research and development (R&D) as potential sources of innovation which in turn may enhance labour productivity. Based on Italian firm-level data they show that R&D and ICT contribute directly to labour productivity but also indirectly through enabling innovation. Empirical evidence also shows that the relationship between ICT and firm performance is heterogeneous with respect to firms and industries, i.e. some firms or industries are more successful in exploiting ICT than others. Chun et al. (2008) analyse the relationship between ICT intensity and performance heterogeneity for a panel of U.S. firms from 1971 to 2000. They find that heterogeneity in firm performance (i.e. variability in stock return and sales growth) is positively and significantly correlated with ICT intensity (measured as ICT capital relative to total capital) and that firm heterogeneity is associated with faster

productivity growth at the industry level. They consider this result as evidence of creative destruction (i.e. increased competition) at the firm level. That is, through their use of ICT, more productive firms displace less productive firms. In a more recent and related paper, Chun et al. (2014) demonstrate that firm heterogeneity leads to more R&D investment which in turn leads to higher long-run growth.

Besides leading to increased heterogeneity in firm performance, ICT itself is a heterogeneous concept. Some studies take account of this fact and analyse the effects of ICT infrastructure or of specific types of ICT. For the case of broadband infrastructure, for example, Grimes et al. (2012) find for New Zealand that firms with broadband internet have a significantly higher labour productivity. By contrast, Bertschek et al. (2013) find a positive and significant effect of broadband internet on German firms' innovation activity but not on their labour productivity. The results by Polder et al. (2010) for the Netherlands suggest that broadband internet is particularly important for services firms. Engelstätter (2013), using German firm-level data, reveals that productivity gains based on enterprise system usage can be maximized by jointly employing three widely established enterprise software systems, i.e. Enterprise Resource Planning (ERP), Supply Chain Management (SCM), and Customer Relationship Management (CRM).

Up until now, there is no analysis explaining whether ICT-induced productivity gains help firms enduring or surviving the current European economic and financial crisis. Given that ICT capital deepening was responsible for up to 27 percent of the increase in European labour productivity in the beginning of this century (van Ark and Inklaar, 2005) it seems natural to consider its potential for fostering recovery. Our work aims at contributing to this debate by providing evidence which is based on micro-aggregated data.

3 Data

This section describes the Micro Moments Database (MMD), the sample we derive from it and presents first descriptive evidence on the role of ICT for the resilience of firms during a period of economic crisis.

3.1 The Micro Moments Database

The data used in this study come from the Micro Moments Database (MMD).[1] The MMD has been created through a series of international collaborative projects of national statistical offices.[2] In each country the following firm-level data sets were linked: the Community Innovation Surveys, (below called IS), the Survey on ICT usage and e-commerce in enterprises (EC), the Structural Business Survey or Production Survey (PS) and the underlying business register (BR). Using the linked firm-level data a common computer code was used to create aggregated data at the industry level and combined it into a harmonized cross-country database. The database includes measures of ICT usage and innovative activity together with measures of business performance and industry dynamics. A big advantage and unique feature of the database is that it not only provides industry-level aggregates but also contains aggregates created for subsets of firms within an industry, such as e.g. firms using ICT more or less intensively.[3] Although other breakdowns are available, for the empirical applications in this paper we mainly exploit this distinction between ICT-intensive and non-ICT-intensive firms and compare their developments over time.

Our empirical analysis consists of two parts: one which compares the productivity developments of firms and one which compares the innovation activity. The productivity analysis is based on a combined sample of firms surveyed both within the Production Survey (PS) and the Survey on ICT usage and e-commerce in enterprises (EC). It covers up to twelve countries (AT, DE, DK, FI, FR, IE, IT, NL, NO, SE, SI, UK), seven industries ('Electronic machinery, post and telecommunication services', 'Consumer manufacturing', 'Intermediate manufacturing', 'Investment goods, excluding hightech', 'Distribution', 'Finance and business, except real estate', 'Personal services'), two subgroups (ICT-intensive and non-ICT-intensive firms) and 10

[1] More information about the database is provided in the Data Appendix. This description is based on Bartelsman et al. (2016) as well as the technical documentation (see Bartelsman et al., 2013a).

[2] Specifically, the ESSnet projects Linking of Microdata on ICT Usage (ESSLimit), and Linking of Microdata to Analyse ICT Impact (ESSLait).

[3] The distributed micro data methodology and the resulting MMD is not the only way to allow cross-country analysis of firm-level data. Commercially available sources, such as ORBIS from Bureau van Dijk are sourced from Chamber of Commerce or mandatory filings of publically traded firms. However, the coverage and sources vary significantly across countries and it is costly to combine these data with other firm-level indicators.

years (2001 - 2010), which results in an unbalanced panel of up to 866 observations. Numerical variables include 'nominal value added' and 'gross output', 'full-time employment', the 'total wage-bill', 'nominal expenditures on intermediates' and a 'capital service measure'. In addition, it includes derived variables such as 'gross output based labor productivity'. Firms are classified as ICT-intensive and non-ICT-intensive based on a variable named 'BROADCAT', which is equal to zero (non-ICT-intensive firm) if the firm has no broadband access or if less than 40 percent of the workers have access to broadband, otherwise, 'BROADCAT' is equal to one and the firm is classified as ICT-intensive. We use this measure of ICT-intensity since common alternatives like PC use or internet access in general might be not very informative anymore, since their use and adoption is meanwhile nearly universal, whereas with respect to the access to fast internet and the share of workers having internet access there is still a high heterogeneity.

For the innovation analysis the same classifier for the distinction between ICT-intensive and non-ICT-intensive firms is used. However, the sample here consists of firms surveyed both for the Community Innovation Surveys (IS) and the Survey on ICT usage and e-commerce in enterprises (EC). It covers only 10 countries (since for Germany and the UK no data are available) but the same set of industries, subcategories and years.[4] The main outcome variables for this analysis are 'product innovations' (inpd) and 'process innovations' (inps). Further control variables, which reduce the sample size, include a measure of 'total innovation expenditures' (rtot) and a measure of 'cooperation arrangements on innovation activities' (co). Table 5 in the Appendix provides further details.

3.2 Descriptive Evidence

Table 1 presents summary statistics for the productivity growth of both ICT-intensive and non-ICT-intensive firms and compares their development for the pre-crisis and crisis period. It confirms the dramatic overall productivity decline during the economic crisis, showing that productivity for the 12 countries covered was increasing by 3.5 percent annually during the pre-

[4]For four countries however, namely Denmark, France, Ireland and Sweden, the innovation data is available from 2006 on.

crisis period (2002 - 2007), but was negative during the economic crisis, resulting in productivity slowdown of 1.1 percent a year. Comparing ICT-intensive and non-ICT-intensive firms, the results show that during the pre-crisis period (2002 - 2007) the average annual productivity growth of the former ones was positive (0.4 percentage points) but lower than that of non-ICT-intensive firms. The latter group increased its productivity on average by 1.3 percentage points a year. Thus, non-ICT-intensive firms increased their relative productivity by 0.9 percent annually in the years preceeding the crisis, compared to their ICT-intensive counterparts. Given the productivity-enhancing character of ICT this might be surprising. However, as Table 6 shows, ICT-intensive firms are more productive than their non-ICT counterparts in both the pre crisis and the crisis period. Also, during the crisis this development of productivity growth was reversed, since during that time ICT-intensive firms experienced a much lower reduction in their productivity growth rate. The productivity of ICT-intensive firms decreased by only 0.5 percentage points a year during the crisis, whereas that of non-ICT-intensive firms decreased by 2.3 percentage points. This suggests that ICT-intensive firms, despite a lower productivity growth trend, were hit less hard during the crisis, compared to non-ICT-intensive firms. Their productivity growth rate during the crisis was 0.9 percentage points lower than that of the pre-crisis period whereas that of non-ICT-intensive firms decreased by 3.6 percentage points. This finding holds not only for the total economy but also for most of the industries examined. Only for 'Investment goods, excluding hightech' (InvesG) and 'Finance and business, except real estate' (FinBu) the relative productivity of non-ICT-intensive firms has improved during the crisis compared to the pre-crisis period.

4 Is Resilience Linked to ICT Use?

This section examines econometrically the link between firms' productivity growth during the crisis and their ICT intensity. If ICT are a driving force behind firms' resilience in times of crisis, then those firms which use ICT more intensively should exhibit smaller productivity decreases than those using ICT less intensively. To study this relationship, we exploit the unique feature of the MMD, which allows comparing groups of firms differing in ICT-intensity

Table 1: Labour Productivity Growth by ICT-Intensity - Before and During Crisis

	Pre-Crisis (2002 - 2007)				Crisis (2008 - 2010)			
Productivity Growth	All	Non-IT	IT	Δ	All	Non-IT	IT	Δ
Consumer manufacturing	2.9	0.6	-0.7	-1.3	2.8	-0.1	3.2	3.3
Investment goods, excl. hightech	4.7	3.8	1.2	-2.6	-6.9	-3.3	-7.5	-4.2
Intermediate manufacturing	4.1	1.9	1.3	-0.6	1.1	-3.4	0.3	3.7
Finance and Business, except real estate	-0.4	-3.5	0.8	4.4	-2.2	-2.5	-1.5	1.1
Distribution	4.6	0.5	0.8	0.3	-0.7	-3.7	-0.4	3.4
Personal Services	2.7	1.9	-4.3	-6.2	-2.3	1.9	-0.9	-2.7
Electrical machinery, post and telecom services	5.1	3.8	1.1	-2.7	1.1	-4.3	4.6	8.9
All industries	3.5	1.3	0.4	-0.9	-1.1	-2.3	-0.5	1.8

Notes: The table contains unweighted average annual percentage labour productivity growth rates by industry for the full sample of countries covered (12 countries) as well as for two periods (2002 - 2007 and 2008 - 2010). For both periods it displays the average growth rate for all firms (All) within an industry, for non-ICT-intensive firms (Non-IT) and for ICT-intensive firms (IT). In addition it shows the differences in growth rates between non-ICT-intensive and ICT-intensive firms (Δ). Also, values for the full sample (row All industries) are given.

within the same industry. Previous studies were either only able to compare ICT-intensive industries with less ICT-intensive industries, thereby ignoring within-industry heterogeneity, or had to rely on firm-level data, which typically precludes cross-country comparisons.

4.1 Difference-in-Difference Estimates

Following McGuckin and Stiroh (2001) and Stiroh (2002) the main approach we apply is a difference-in-difference methodology, which uses a binary classification of ICT-intensive firms and compares their relative productivity level or development to that of other firms. The approach is useful, as Stiroh (2002) suggests, because it is robust to how ICT are measured, but is limited in that it does miss variation in ICT-intensity across firms.

Difference-in-difference estimation extends the test for differences in means with an additional constant and interaction term for the group of ICT-intensive firms. The main estimation equation, in growth rates, is:

$$\Delta \ln LP_{ijt}^{GO} = \alpha + \beta D_t^{Crisis} + \gamma D_{ij}^{ICT} + \delta D_t^{Crisis} \times D_{ij}^{ICT} + \theta \Delta \ln X_{ijt} + \epsilon_{ijt}, \tag{1}$$

where $D_t^{Crisis} = 1$ if $2007 < t < 2010$ and $D_t^{Crisis} = 0$ otherwise as well as $D_{ij}^{ICT} = 1$ if subgroup contains the ICT-intensive firms and $D_{ij}^{ICT} = 0$ otherwise. $\Delta \ln LP_{ijt}^{GO}$ represents gross output-based labor productivity growth of country-industry combination i, j denotes the

group of ICT- and non-ICT intensive firms within i and t represents the respective year. The vector X_{ijt} contains a set of control variables such as capital, labor and intermediate inputs. α is the mean growth rate for non-ICT-intensive firms in the non-crisis period (before 2008 and in 2010), whereas $\alpha + \gamma$ equals the growth rate of ICT-intensive firms during that time. β captures the reduction in productivity growth during the crisis for non-ICT-intensive firms, whereas $\beta + \delta$ is the change for ICT-intensive firms. The coefficient of interest is δ, since it represents the difference in the adjustment during the crisis, i.e. it can be considered a measure of differences in the resilience between ICT- and non-ICT-intensive firms. Standard errors are corrected for heteroscedasticity and for correlation across industries within countries.

Table 2 contains our baseline results describing the link between ICT-intensity and productivity during the times of crisis. It exhibits eight columns, where the first two columns contain specifications with labour productivity levels as the dependent variable. In column 1 the productivity level is explained by the crisis-dummy, the ICT-dummy, their interaction and our three inputs: capital, labour and materials. In addition, we include country and industry dummies. All variables, except the capital coefficient, are significant. The crisis dummy, as expected, shows a strongly negative and significant coefficient. In contrast, the interaction-term, the variable of interest, is positive and significant, equal to 0.157, indicating that during the crisis in 2008 and 2009 the productivity of ICT-intensive firms relative to that of the other firms has increased by around 15.7 percent. More precisely, the results indicate that during the crisis non-ICT-intensive firms suffered from a productivity decline of around 10.2 percent, whereas ICT-intensive firms experienced a slight improvement in productivity levels on average. In specification 2, we include country-industry-subcategory fixed effects to control for the mean productivity levels of each entity. Doing so results in very similar findings.

Columns 3 to 8, by applying specifications in growth rates, also largely confirm these findings. Compared to the specifications in levels, which control for permanent differences in labour productivity levels between groups, e.g. among ICT- and non-ICT-intensive firms, specifications in growth rates control, through fixed effects, for differences in growth trends of groups. Such differences in productivity trends, if they exist and are not controlled for, could drive

Table 2: Labour Productivity and IT - Baseline Results

	Labour Productivity		Labour Productivity Growth					
	1	2	3	4	5	6	7	8
D^{Crisis}	-0.102***	-0.119***	-0.129***	-0.141***	-0.124**	-0.133***	-0.141***	-0.108***
	(-6.83)	(-6.61)	(-4.54)	(-3.88)	(-2.83)	(-4.86)	(-4.02)	(-3.89)
$D^{Crisis} \times D^{ICT}$	0.157***	0.144***	0.100*	0.114*	0.098*	0.105***	0.119*	0.054**
	(5.41)	(5.11)	(2.26)	(2.03)	(1.95)	(4.36)	(2.21)	(2.95)
D^{ICT}	0.212***		-0.012					
	(4.01)		(-0.44)					
ln_k_avg	-0.022	-0.011						
	(-0.46)	(-0.58)						
ln_e_avg	-0.471***	-0.297***						
	(-7.38)	(-6.73)						
ln_nm_avg	0.533***	0.390***						
	(6.22)	(9.35)						
dln_k_avg			-0.035***	-0.037***	-0.012		-0.039***	-0.041***
			(-4.34)	(-4.58)	(-0.51)		(-3.58)	(-7.31)
dln_e_avg			-0.116***	-0.101***	-0.133**		-0.141***	-0.108***
			(-3.86)	(-4.03)	(-2.84)		(-3.74)	(-4.57)
dln_m_avg			0.278***	0.262***	0.254**		0.308***	0.252***
			(6.43)	(7.88)	(2.95)		(7.63)	(7.39)
dln_hkpct					0.138			
					(1.00)			
dln_k_e						0.013		
						(0.75)		
dln_m_e						0.144***		
						(5.85)		
Country-Subindustry FE	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	No	Yes	No	No	No	No	No
Industry FE	Yes	No	Yes	No	No	No	No	No
Sample	Full	Full	Full	Full	Full	CRS	No Elecom	No FRA
R^2	0.88	0.35	0.28	0.27	0.29	0.20	0.30	0.25
N	824	824	824	824	627	645	705	779

Notes: This table analyzes the relationship between ICT-intensity and labour productivity levels / growth rates during and before the crisis. In the first two columns the dependent variable is the log labour productivity level, whereas in columns 3 to 8 it is labour productivity growth. Specifications 1 and 3 are estimated using OLS, whereas the remaining specifications are estimated using an FE-estimator. The sample covers in specification 1 to 6 all countries, industries, subgroups and years, whereas specification 7 excludes observations from the industry Elecom whereas specification 8 excludes France. In column 6 we assume constant returns to scale by using capital and material intensities (i.e. capital and materials divided by employment) as input variables. Heteroscedasticity-robust t-values are provided in parentheses, which are corrected for clustering of observations at the country level. ***, **, *: Significantly different from 0 at the 1%, 5%, and 10% levels, respectively. All regressions are weighted by the country-industry-subgroup specific average full-time equivalent employment.

the findings of the levels specification. If e.g. ICT-intensive firms have on average a higher productivity growth rate, then a specification in levels would indicate that ICT-intensive firms compared to non-ICT-intensive ones have in later periods a relatively higher productivity level, and thus would indicate that they were hit less strongly by the crisis just because of the difference in growth trends and not because of a higher resilience during the crisis. Column 3 provides a simple specification without country-industry-subcategory fixed effects, which results again in a negative significant coefficient for the crisis-dummy, indicating that the productivity growth of non-ICT-intensive firms during the crisis was lower than in the pre-crisis period. The ICT-dummy is insignificant which indicates that there is on average no difference in the productivity growth rate between those two groups of firms. However, the interaction term is significant and positive, which suggests, despite the insignificant difference in the pre-crisis growth rates of ICT- and non-ICT-intensive firms, that the relative growth rate of ICT-intensive firms during the crisis increased. Just as in the levels specifications, this suggests that ICT-intensive firms were hit less strongly during the crisis. Column 4, controlling for country-industry subindustry average labour productivity growth rates, capital, labor and intermediate input growth rates, results in similar findings, where again the crisis dummy is, as can be expected, negative significant, whereas the interaction term is positive significant. The labor and intermediate input variables show significant signs in line with values which can be expected from production theory. In contrast, for capital we find a negative value, whereas theory suggests that it should be positive.[5] However, as the following robustness checks show, the negative capital coefficient becomes insignificant and disappears in several alternative specifications. In column 5 we add the share of workers with higher formal education as a control variable, which is important to capture potential sources of omitted variables related to complementary inputs to ICT, such as high-skilled labor. Column 6 restricts the production technology to constant returns to scale by replacing the input levels with capital and materials intensities (i.e. capital and intermediate

[5]This could be the consequences of a downward bias due to the endogeneity of capital. We also tested whether the negative coefficient is due to multi-collinearity problems between our ICT variable and the capital services measure. Since capital services, in contrast to a capital stock measure, weight capital assets such as ICT more strongly, the growth rate of the capital services measure could be closely correlated with firms' ICT intensity. However, excluding the ICT variable from the regression did not affect the sign and significance of the capital coefficient.

input levels divided by the employment level). Doing so does not change our conclusion with respect to the role of ICT during the crisis. Column 7 studies the robustness of our results towards the exclusion of the Elecom industry, i.e. the ICT-producing industry. The results confirm our previous findings and thus suggest that our findings are not driven by the ICT-producing sector. Column 8 excludes France, since for this country there is only data available from 2007 onwards, and including it makes the sample highly unbalanced. All specifications confirm the baseline findings from column 4, indicating that ICT-intensive firms seem to be hit less during the crisis and thus seem to be more resilient to an economic crisis.

The next subsection aims at providing evidence on a potential explanation for these findings, namely on potential differences of ICT- and non-ICT-intensive firms with regard to their innovation behavior during the crisis. Following that, subsection 4.3 provides further robustness checks aimed at establishing the main results more rigorously.

4.2 A Potential Explanation: Process Innovations

ICT have frequently been shown to improve firms' capacity to innovate. This section aims at providing evidence on whether ICT-intensive and non-ICT-intensive firms were differing with respect to their innovation behavior during the crisis and whether their relative innovativeness changed in that time. If this would be the case, it could help explaining why ICT-intensive firms were hit less strongly with respect to productivity during the crisis. Indeed as Table 3 shows, there are differences between ICT-intensive and non-ICT-intensive firms with respect to product and process innovativeness. During the pre-crisis period ICT-intensive firms were more innovative, i.e. ICT-intensive firms have implemented more new processes and introduced more new or significantly improved products or services. Half of the ICT-intensive firms had introduced product innovations during the pre-crisis period, whereas only 35 percent of non-ICT-intensive firms did so. For process innovations the difference is smaller: 42 percent of ICT-intensive firms did introduce innovative processes, whereas 36 percent of non-ICT-intensive firms had a process innovation. These differences, however, at least for process innovations were amplified during the crisis period. For product innovations, the innovation gap of 14 percent

points between ICT-intensive and non-ICT-intensive firms increased to 16 percent points. For process innovations this change was more pronounced, whereas before the crisis the difference between those two groups of firms was equal to 6 percentage points, it increased to 10 percentage points during the crisis.

Table 4 contains estimation results disentangling the effect of ICT intensity, the crisis and, their joint effect on innovation rates. The results confirm the previous findings. Columns 1 to 4 contain estimates for product innovations, whereas columns 5 to 8 contain those for process innovations. Column 1 and 5 which do not contain country-industry-subgroup fixed-effects show that the group of ICT-intensive firms are on average more innovative both in terms of product and process innovations. As the summary statistics indicate, firms became less innovative during the crisis, but only slightly. For product innovations, the baseline specification (column 2) allowing for country-industry-subgroup-specific fixed-effects indicates that firms on average decreased innovations by around 3 percentage points. This finding also holds if the 'Elecom' industry is neglected (column 3), but becomes insignificant if Austria and Finland, the two countries showing during the crisis the largest difference in innovation performance between ICT- and non-ICT-intensive firms, are excluded from the estimation sample (column 4).

For process innovations, we also find only in one out of four specifications a significant reduction in the share of innovating firms. Most interestingly, however, we find for process innovations in all four specifications a positive, significant interaction effect, indicating that during the crisis, ICT-intensive firms were able to increase their relative innovativeness with respect to processes. For product innovations, however, we find no significant interaction effect, indicating that, although ICT-intensive firms are more innovative overall, there is no significant change during the crisis with respect to the relative innovation behavior of ICT-intensive and non-ICT-intensive firms there.

The results suggest that ICT-intensive firms did introduce process innovations during the crisis at the same rate as before the crisis, whereas non-ICT-intensive firms slightly reduced their innovation activity. Process innovations, in contrast to product innovations, could therefore explain, at least to some extent, why ICT-intensive firms experienced a smaller reduction in

Table 3: Product & Process Innovation by IT-Intensity Before and During Crisis

	Pre-Crisis (2002 - 2007)				Crisis (2008 - 2010)			
Product Innovation	All	Non-IT	IT	Δ	All	Non-IT	IT	Δ
Pers	0.16	0.15	0.23	0.08	0.20	0.18	0.21	0.04
InvesG	0.59	0.53	0.70	0.17	0.54	0.46	0.62	0.17
IntmdG	0.44	0.41	0.51	0.11	0.43	0.36	0.51	0.15
FinBu	0.36	0.29	0.39	0.10	0.37	0.26	0.40	0.13
Elecom	0.58	0.47	0.66	0.19	0.61	0.45	0.69	0.23
Distr	0.23	0.16	0.31	0.15	0.28	0.20	0.33	0.13
ConsG	0.46	0.42	0.59	0.17	0.46	0.39	0.58	0.19
All	0.41	0.35	0.50	0.14	0.42	0.33	0.49	0.16
Process Innovation	All	Non-IT	IT	Δ	All	Non-IT	IT	Δ
Pers	0.17	0.16	0.23	0.08	0.26	0.21	0.33	0.12
InvesG	0.47	0.46	0.50	0.04	0.46	0.39	0.52	0.13
IntmdG	0.47	0.45	0.50	0.05	0.44	0.39	0.49	0.09
FinBu	0.32	0.29	0.34	0.05	0.34	0.24	0.36	0.12
Elecom	0.46	0.43	0.47	0.04	0.47	0.43	0.49	0.05
Distr	0.29	0.24	0.34	0.09	0.30	0.26	0.33	0.08
ConsG	0.43	0.40	0.49	0.09	0.41	0.37	0.49	0.12
All	0.39	0.36	0.42	0.06	0.39	0.34	0.43	0.10

Notes: The table contains average annual shares of firms having introduced in a year a new product or process innovation. It covers the full innovation sample of countries (10 countries) for two periods (2002 - 2007 and 2008 - 2010). For both periods it displays the average shares for all firms (All), for non-ICT-intensive firms (Non-IT) and for ICT-intensive firms (IT). In addition it provides differences between non-ICT-intensive and ICT-intensive firms with respect to their innovation shares (Δ). Also, values for the full sample (row All) and for each industry covered are given.

productivity during the crisis. These findings are in line with the hypothesis that ICT-intensive firms are better able to adapt their production processes through process innovations in times of crisis thereby increasing their resilience and ensuring a higher competitiveness relative to less ICT-intensive firms. In addition, an interpretation could be that in a crisis, demand is becoming tight and it makes less sense to expand through (product) innovation. So to become more productive a firm needs to work on cost efficiency (process innovation). It makes sense that ICT-intensive firms can implement these more easily, for example through their superior digitally supported and interconnected business functions.

4.3 Robustness Checks

In order to establish the robustness of the main results more rigorously, we provide additional results describing the relationship between ICT-intensity, the economic crisis and firms' productivity.

Table 4: Product and Process Innovation - Baseline Results

	Product Innovation				Process Innovation			
	1	2	3	4	5	6	7	8
D^{Crisis}	-0.021	-0.031*	-0.035*	-0.031	-0.023	-0.033	-0.038*	-0.029
	(-1.30)	(-2.10)	(-2.25)	(-1.77)	(-1.18)	(-1.77)	(-1.96)	(-1.37)
$D^{Crisis} \times D^{ICT}$	0.014	0.020	0.017	0.023	0.037**	0.036**	0.038*	0.034**
	(0.72)	(1.19)	(1.08)	(1.15)	(2.58)	(2.95)	(2.21)	(2.45)
D^{ICT}	0.144***				0.066***			
	(16.26)				(7.35)			
Country-Subindustry FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Weighted	No	No	No	No	No	No	No	No
Sample	Full	Full	No Elec.	No AT,FI	Full	Full	No Elec.	No AT,FI
R^2	0.15	0.02	0.02	0.01	0.07	0.02	0.02	0.01
N	718	718	614	616	718	718	614	616

Notes: This table analyzes the relationship between ICT-intensity and product / process innovation during and before the crisis. In the first four columns the dependent variable is the share of firms having introduced a new or significantly improved good/service onto the market, whereas in columns 5 to 8 it is the share of firms having introduced new or significantly improved processes. Specifications 1 and 5 are estimated using OLS, whereas the remaining specifications are estimated using an FE-estimator. The sample covers all countries, industries, subgroups and years, whereas specification 3 and 7 exclude observations from the 'Elecom'-industry and specification 4 and 8 exclude observations from Austria and Finland. Heteroscedasticity-robust t-values are provided in parentheses, which are corrected for clustering of observations at the country level. ***, **, *: Significantly different from 0 at the 1%, 5%, and 10% levels, respectively.

Table 7 provides evidence indicating that the relationship between ICT intensity and firms' performance during the crisis is driven mainly by service industries. To analyze differences between manufacturing and service industries, we split our sample into manufacturing industries (ConsG, IntmdG, InvesG) and service industries (Distr, FinBu, Pers). Columns 1 to 4 contain only observations from manufacturing industries whereas columns 5 to 8 contain only observations from service industries. Each specification contains a different (sub)set of industries. Surprisingly, in each of the four specifications covering manufacturing industries, the interaction term becomes insignificant whereas in each of the four specifications covering service industries the interaction term remains positive and significant. This indicates that our findings with respect to the role of ICT for firms' resilience is mainly driven by service industries.

Table 8 provides specifications aimed at testing the robustness of the results with respect to the definition of the economic crisis. To exclude the possibility that our results are driven by factors correlated with the economic crisis, but are not caused by it directly, we repeat our baseline specification using alternative crisis dummies. In specification 1, we define the crisis

period only as the year 2009, which however does not affect our results in a qualitative way. The crisis dummy remains negative and highly significant whereas the interaction term is positive and significant. Specification 2 contains a measure of the crisis that is more broadly defined as the period between 2008 and 2010, thus includes a year which is typically already denoted as a post-crisis year. Doing so, we still find significant, but slightly weaker results, in particular the interaction term remains only slightly significant. This trend is even more amplified in the following columns, where we add the year 2007 (column 3) and even 2006 (column 4) as 'artificial' crisis years. In both columns both the crisis dummy and the interaction are insignificant. Thus, these results indicate that our results are closely related to the crisis and do not reflect broader trends which existed before or after the crisis. Columns 5 and 6 provide further evidence by interacting our two variables of interest with another dummy which is equal to one if a country was hit particularly strong by the crisis. In column 5, the additional dummy is equal to one if the country experienced a productivity decline in 2008 or 2009 of more than one percent, whereas in column 6 it is equal to one if the decline was bigger than five percent. Unsurprisingly, in both specifications the crisis dummy for countries strongly hit is highly negative and significant. At the same time, also for other countries the crisis dummy remains negative, although at a lower level of significance. Reassuringly, the interaction term of interest, the one between the crisis dummy and the ICT-intensity dummy remains in column 5 positive and significant but becomes insignificant in column 6. More interestingly, the interaction term of the crisis dummy for countries that were hit hard by the crisis with the ICT-intensity dummy is also positive, although insignificant. This indicates that in countries which were hit more strongly by the crisis the ICT-intensive firms showed an even stronger resilience, such that the gap between ICT-intensive and non-ICT-intensive firms increased there even more than in the other countries.

Taken together, our results are robust with respect to the use of alternative sets of controls and are clearly related to the (strength) of the crisis. Overall, ICT-intensive firms have been more resilient during the crisis relative to firms which use ICT less intensively, a result that is particularly driven by the service sector.

5 Conclusion

For firms, industries and countries, ICT are considered a potential driver of resilience in times of an economic crisis. To analyze this question, we exploit a novel and unique cross-country cross-industry meso-level panel data set, the Micro-Moments Database. In contrast to standard macroeconomic data these data allow to distinguish between ICT-intensive and non-ICT-intensive firms within industries in a cross-country setting. Applying a difference-in-difference framework we find evidence that strengthens the idea of ICT-related resilience. The results show that ICT-intensive firms, relative to less ICT-intensive ones, were hit less hard during the economic crisis in 2008 and 2009. Firms using ICT more intensively improved their relative productivity. In addition, they were also more innovative with respect to process innovations (but not with respect to product innovations). This result indicates that ICT allow firms adjusting their production processes more easily during a crisis and in that way improving their relative productivity and thus their competitiveness. Our results provide evidence in favor of the hypothesis that ICT make firms and industries more resilient in times of crisis.

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7 Appendix

7.1 Data Appendix

Setting up firm-level datasets for multi-country research is difficult and costly because most of the firm-level information that is collected by national statistical agencies is confidential.[6] This means that the legal framework protecting the data does not allow for direct analysis on a merged cross-country firm-level dataset. In the past decade, several projects have been using the method of distributed micro data analysis as developed by Bartelsman et al. (2009) to conduct cross-country research using firm-level information. In this approach, depicted in Figure 1, a common protocol is used to extract information from each countries' harmonised firm-level datasets. This involves the assembly of micro-data by participating national statistical offices (NSO), and the running of the same program code in each country to retrieve the indicators and statistical moments or to conduct statistical analyses. By proceeding in this way, the cross-country MMD containing harmonized indicators of underlying distributions and correlations can be made public without breaking national rules of confidentiality.

The MMD has been created through international collaborative projects of national statistical offices. The description below summarizes the technical documentation by Bartelsman et al. (2013a). The projects harmonized the firm-level linking in each country of the Community Innovation Surveys, (below called IS), the Survey on ICT usage and e-commerce in enterprises (EC), the Structural Business Survey or Production Survey (PS) and the underlying business register (BR). Using the linked firm-level sources, each statistical agency ran common computer code, the results of which were ultimately combined into a cross-country datasets at a meso-level of industry disaggregation that include measures of ICT usage and innovative activity together with measures of business performance and industry dynamics. These measures include typical aggregates, such as sums and means, but also higher moments of distributions of variables of interest, as well as joint moments from multivariate distributions. Further, information is aggregated not just over firms in an industry, but also over subsets of firms in an industry, for

[6] This subsection describing distributed micro data analysis and the micro moments database has been taken from Bartelsman et al. (2016).

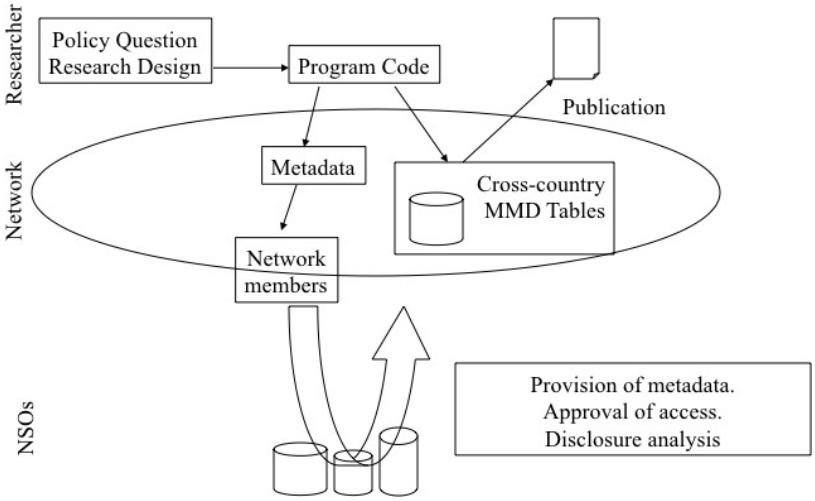

Figure 1: Distributed Micro Data Analysis

example by size or age, or by innovation characteristics.

The MMD is composed of a set of related cross-country tables. There are tables that provide metadata and coverage information about the underlying datasets, tables with firm demographics (birth, death, size, age) based on the BR, tables of summary statistics from each underlying survey, PS, EC, and IS, and combined survey samples (e.g. PS-EC, IS-EC or PS-EC-IS), a table with industry dynamics indicators, and a set of tables with detailed information on distributions and joint distributions of variables.

7.2 Additional Tables

Table 5: Raw Data Description

Variable	Name in Raw Data	Description
Sample: PSEC		
LP^{GO}	LPQ	Gross output based labour productivity (deflated gross output per employee)
k	K	Capital services measure
e	E	Full-time equivalent employment
m	NM / P_M	Deflated expenditures on intermediates
hkpct	HKPCT	Percentage of workers with higher formal education
	BROADPCT	Percentage of workers with access to broadband
Sample: ECIS		
inpd	INPD	Introduced onto the market a new or significantly improved good/service
inps	INPS	Introduced new or significantly improved process

Notes: This table contains a description of all raw variables used, including the official symbol used by the MMD database.

Table 6: Labour Productivity Level - Summary Statistics

	Pre-Crisis (02-07)				Crisis (08-10)			
	All	Non-IT	IT	Δ	All	Non-IT	IT	Δ
Personal Services	109.61	82.04	150.08	68.04	107.98	81.72	153.99	72.27
Investment goods, excl. hightech	189.18	173.78	217.92	44.14	191.17	161.81	208.73	46.92
Intermediate manufacturing	206.91	175.77	285.20	109.43	214.94	167.37	279.99	112.62
Finance and Busin., excpt. real estate	148.32	94.70	179.05	84.35	125.86	70.02	147.42	77.40
Electr. mach., post and telecom. serv.	203.64	139.82	251.91	112.10	281.29	141.84	343.80	201.96
Distribution	297.26	215.86	401.06	185.20	313.13	183.68	407.29	223.61
Consumer manufacturing	203.07	176.84	313.53	136.70	229.30	184.86	329.95	145.09
All industries	199.96	155.92	261.82	105.90	211.33	147.79	268.83	121.03

Notes: The table contains average annual labour productivity levels by industry for the full sample of countries covered (12 countries) as well as for two periods (2002 - 2007 and 2008 - 2010). For both periods it displays the average level for all firms (All) within an industry, for non-ICT-intensive firms (Non-IT) and for ICT-intensive firms (IT). In addition it shows the differences in levels between non-ICT-intensive and ICT-intensive firms (Δ). Also, values for the full sample (row All industries) are given.

Table 7: Labour Productivity Growth - Manufacturing and Services

	Manufacturing				Services			
	1	2	3	4	5	6	7	8
D^{Crisis}	-0.104*	-0.141**	-0.101	-0.063	-0.163***	-0.142***	-0.155***	-0.166***
	(-1.83)	(-2.31)	(-1.55)	(-1.18)	(-5.24)	(-5.41)	(-4.48)	(-5.28)
$D^{Crisis} \times D^{ICT}$	0.029	0.061	0.022	-0.004	0.171*	0.132*	0.226**	0.169*
	(0.63)	(1.45)	(0.39)	(-0.10)	(2.20)	(1.98)	(3.02)	(2.18)
dln_k_avg	-0.054	-0.055	-0.073*	-0.030	-0.030***	-0.059***	0.008	-0.031***
	(-1.80)	(-1.64)	(-2.21)	(-1.04)	(-3.61)	(-3.90)	(0.54)	(-4.02)
dln_e_avg	-0.189***	-0.207***	-0.167**	-0.176***	-0.148**	-0.233**	-0.111	-0.135**
	(-5.82)	(-4.05)	(-2.83)	(-4.86)	(-2.95)	(-2.88)	(-1.23)	(-2.43)
dln_nm_avg	0.302***	0.301***	0.293***	0.311***	0.346***	0.528***	0.199**	0.335***
	(7.21)	(5.63)	(5.20)	(5.54)	(3.91)	(4.64)	(2.76)	(3.73)
Country-Subindustry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	No	No	No	No	No	No	No	No
Industry FE	No	No	No	No	No	No	No	No
Weighted	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ConsG	✓		✓	✓				
IntmdG	✓	✓		✓				
InvesG	✓	✓	✓					
Distr					✓	✓		✓
FinBu					✓		✓	✓
Pers					✓	✓	✓	
R^2	0.37	0.44	0.35	0.33	0.29	0.42	0.13	0.28
N	364	262	221	245	341	227	208	247

Notes: This table analyzes the relationship between ICT-intensity and labour productivity growth rates during and before the crisis for manufacturing and service industries separately. Columns 1 to 4 contain only observations from manufacturing industries whereas columns 5 to 8 contain only observations from service industries. Each specification contains a different (sub)set of industries. Heteroscedasticity-robust t-values are provided in parentheses, which are corrected for clustering of observations at the country level. ***, **, *: Significantly different from 0 at the 1%, 5%, and 10% levels, respectively. All regressions are weighted by the country-industry-subgroup specific average full-time equivalent employment.

Table 8: Labour Productivity Growth - Alternative Measures of the Crisis

	1	2	3	4	5	6
$D^{Crisis09}$	-0.157***					
	(-5.72)					
$D^{Crisis09} \times D^{ICT}$	0.035**					
	(2.53)					
$D^{Crisis0810}$		-0.114***				
		(-3.88)				
$D^{Crisis0810} \times D^{ICT}$		0.102*				
		(1.88)				
$D^{Crisis0710}$			-0.024			
			(-1.59)			
$D^{Crisis0710} \times D^{ICT}$			0.006			
			(0.27)			
$D^{Crisis0610}$				0.008		
				(0.59)		
$D^{Crisis0610} \times D^{ICT}$				0.007		
				(0.25)		
D^{Crisis}					-0.057*	-0.058*
					(-1.98)	(-2.10)
D^{Crisis_fl}					-0.128**	
					(-3.19)	
$D^{Crisis} \times D^{ICT}$					0.052*	0.046
					(2.04)	(1.79)
$D^{Crisis\_fl} \times D^{ICT}$					0.093	
					(1.35)	
D^{Crisis_fl2}						-0.129**
						(-3.19)
$D^{Crisis\_fl2} \times D^{ICT}$						0.102
						(1.38)
dln_k_avg	-0.035***	-0.034***	-0.032**	-0.028**	-0.039***	-0.039***
	(-3.35)	(-3.31)	(-3.16)	(-2.90)	(-5.44)	(-5.59)
dln_e_avg	-0.086***	-0.122***	-0.132***	-0.137***	-0.106***	-0.106***
	(-3.70)	(-4.72)	(-4.85)	(-4.58)	(-4.09)	(-4.12)
dln_nm_avg	0.240***	0.278***	0.295***	0.296***	0.256***	0.255***
	(6.97)	(8.16)	(6.21)	(6.06)	(7.12)	(7.13)
Country-Subindustry FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	No	No	No	No	No	No
Industry FE	No	No	No	No	No	No
Weighted	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Full	Full	Full	Full	Full	Full
R^2	0.24	0.27	0.18	0.18	0.29	0.29
N	824	824	824	824	824	824

Notes: This table analyzes the relationship between ICT-intensity and labour productivity growth during and before the crisis. The dependent variable is gross-output based labour productivity growth. In column 1 the crisis is defined as the year 2009. In column 2 it is defined as the years 2008 to 2010. In column 3 the crisis also includes 2007, whereas in column 4 it even includes 2006. In column 5 and 6 the crisis is defined as the years 2008 and 2009. In column 5 we add a dummy equal to one if a country experienced an average productivity decline larger than 1 percent in 2008 or 2009 (D^{Crisis_fl}). In column 6 we add a dummy equal to one if a country experienced an average productivity decline of more than 5 percent in 2008 or 2009. All specifications are estimated using a FE-estimator. In all specifications, the sample covers all countries, industries, subgroups and years. Heteroscedasticity-robust t-values are provided in parentheses, which are corrected for clustering of observations at the country level. ***, **, *: Significantly different from 0 at the 1%, 5%, and 10% levels, respectively. All regressions are weighted by the country-industry-subgroup specific average full-time equivalent employment.