Flattening Hierarchies or Amplifying Control? Longitudinal Evidence on ICT Investments' Effect on Firm Decentralization*

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Abstract

Decentralization as a key organizational feature, plays a critical role in leveraging dispersed knowledge, enhancing communication efficiency, exploiting comparative advantage, and may increase or decrease because of new Information and Communication Technologies (ICT). The existing research on the ICT-decentralization relationship, however, relies on cross-sectional designs that cannot do justice to the changing functions of ICT investments, their evolving role in organizations over time, and the role of firm-specific idiosyncrasies in shaping organizational structures. This paper advances the literature through a longitudinal analysis of the ICT-decentralization relationship that controls for confounding establishment fixed effects and allows for lagged, cumulative predictors and temporal variation. Using a unique panel dataset of over 27,500 establishments observed intermittently between 1998-2021, we find robust evidence that ICT investments lead to an increase in the likelihood of decentralization. This relationship is weaker when we control stable unobserved establishment characteristics and importantly, the average effect of ICT investments diminishes overtime within firms (and further pronounced, for cumulative investments) suggesting that while early ICT (and one-off investments) significantly shift decision-making structures downwards, frontier (and concurrent) technologies investments do so at a decreasing rate—and opposingly, even contribute to (re)centralization. Our findings qualify the uniform decentralization role of ICTs in organizational decision-making and underscore the importance of timing, cumulative dynamics, and scale of ICT investments in shaping the ICT-decentralization relationship.

1. Introduction

Organizations, particularly firms, serve as the fundamental building blocks of modern economies. However, firms face fundamental transformation as information and communication technologies (ICT) reshape how economic activities and value creation are organized and controlled (Brynjolfsson & McAfee, 2014; Malone, 2004). A key organizational feature of firms concerns decentralization and managerial delegation, which play critical roles in leveraging dispersed knowledge, enhancing communication efficiency, and exploiting comparative advantage (Akcigit et al., 2021; Grobovsek, 2020). Theoretically, ICT encompasses a broad category of technologies, comprising hardware, software, networks, and systems that organizations invest in to capture, process, store, and communicate information, which can pull organizations toward both more and less centralized decision-making and concentrated control (Bloom et al., 2014a; Brynjolfsson & McAfee, 2014; Garicano, 2000; George & King, 1991; Gurbaxani & Whang, 1991; Zuboff, 1988). An important empirical question therefore is whether ICT shifts decision-making authority from managers to non-managerial employees, reinforces managerial control, or leaves organizational hierarchies largely unaffected. Answering this question rigorously, however, requires moving beyond the cross-sectional designs that have dominated prior research and are unable to illuminate the causal and dynamic nature of the ICT-decentralization relationship.

This paper helps enhance our empirical understanding of the potentially complex and dynamic impact—positive or negative—of ICT investment on firm (de)centralization. We consider three key issues in studying the ICT-decentralization relationship: unobserved time-invariant firm characteristics and potential reverse causality between (de)centralization and ICT investment, the temporal variation in ICT's (de)centralizing effect and, differentiate between cumulative and one-off ICT investment trajectories. A priori, we expect that ICT investment fosters centralization but that this decentralizing effect has grown weaker with the changing

nature of ICT technologies, e.g., from intranets and email to organization-wide cloud-based systems and algorithmic decision-making. For the empirical analysis, we use comprehensive, nationally representative, longitudinal data from the establishment level survey from Institute for Employment Research (IAB), that has one of longest-running employer surveys. This employer survey has been widely used in recent literature (e.g., Arntz et al., 2023; Caldwell & Danieli, 2024; Gumpert et al., 2022). The sample comprises over 27,500 German establishments and spans the years 1993-2021. The empirical approach employs establishment fixed effects to capture within-unit changes, incorporate lagged and differentiates between cumulative multi-year ICT investment and one-off ICT investment measures, addressing simultaneity and unobserved heterogeneity, and uses the time-series dimension to examine the changing functions of ICT investments and how firms internalize ICT investments .

The results indicate a robust net positive effect of investing in ICT on decentralization, which we measure as downward shifts in responsibilities and decisions. Establishments (interchangeably: firms) that have invested in ICT, or have invested in ICT concurrently (for two years) are more likely to have delegated authority to lower levels. As expected, the longitudinal approach with establishment fixed effects, which accounts for unobserved time-invariant traits, yields a smaller positive effect of ICT investment on decentralization compared to the cross-sectional estimates. Hence, omitted variable bias has likely inflated earlier estimates of ICT's decentralizing effect. In the preferred model with establishment fixed effects, cumulative ICT investments from three- and four-years prior are associated with a 2.4 percentage point higher likelihood of decentralization within the last two years compared to the same firm if it had no ICT investment history in that period. Further results reveal two important features of the ICT-decentralization relationship not considered heretofore. First, the estimated effect of ICT investments declines over calendar time (stronger in earlier years of the sample than in later years). Hence, it seems that while early ICT investments significantly reshape

decision-making structures, subsequent frontier technologies do so at a decreasing rate. This way, modern-day ICT seems to contribute to (re)centralization as well. The time-varying pattern is especially pronounced after 2010, with ICT investments in later cohorts yielding significantly smaller increases in decentralization and with reversal or earlier decentralization These results are seemingly consistent with the understanding that the nature of ICT has changed, with recent ICT systems and tools increasingly facilitating managerial oversight and control rather than decentralization. Second, we find that cumulative/repeated ICT investment patterns are more decentralizing than one-off investments patterns are. . Interestingly, although repeated investments patterns are associated with greater decentralization, the estimates suggest that their marginal effect declines more rapidly over calendar time than the marginal effect of one-off investments. This pattern dampens the overall positive ICT-decentralization relationship. One possible explanation is that while repeated investments involve larger ICT increments, larger ICT investments in later-stage technologies increasingly enable centralized monitoring, limiting their decentralizing potential, relative to earlier-stage technology adoption waves. Overall, we find robust evidence that ICT investments causally promote firm decentralization. At the same time, our results qualify earlier findings by showing that decentralizing effects vary systematically—and attenuate more quickly for repeated investments—over calendar time. The relationship between investing in ICT and organizational structure is nuanced as technologies can both decentralize and (re)centralize decision-making, depending on the use, cumulative dynamics, and the timing or nature of these investments.

This paper resonates with and contributes to different literatures. At the most basic level, this paper fits the long-standing literature on the role of technology in shaping organizational hierarchies and structures and systems of monitoring and control (Chandler, 1962, 1977; Gibbons & Roberts, 2013; McLoughlin et al., 2000; Woodward, 1958). More in specific, the paper contributes to the growing body of research on (contextual) factors promoting and

hindering firm decentralization (Akcigit et al., 2021; Bloom et al., 2012; Caroli & Van Reenen, 2001; Grobovšek, 2020).

Within this body of research, our key contribution is to the discussion on how ICT affects organizational structures, particularly ICT's potential decentralizing effect (e.g., Garicano 2000), which also traces back many decades (Hoos, 1960; Leavitt & Whisler, 1958). Evidence on the (de)centralizing effect of ICT has long been ambiguous, advanced studies such as Bloom et al. (2014) that empirically separate effects of different types of ICT notwithstanding (see George & King (1991) and Wyner & Malone (1996) for early surveys).

To the best of our knowledge, this is one of the first longitudinal, establishment-level studies of ICT and decision-making hierarchy spanning more than two decades. Our analysis extends prior work to make important empirical contributions and provide empirical insights into the dynamic relationship between ICT investments and firm decentralization. The findings show that ICT's organizational consequences depend on both investment patterns and historical context: early-2000s investments are not equivalent to those of the 2010s, as both the technologies and their organizational applications have evolved substantially.

2. Background and Hypotheses Development

2.1. The (De)Centralizing Effect of ICT

Does ICT shift decision-making authority from managers to non-managerial employees, or does it reinforce managerial control? Different theoretical answers to this question exist in various scholarly fields, identifying and emphasizing opposing effects of ICT on centralization and decentralization of authority and decision-making powers in organizations (e.g.,George & King, 1991; Gurbaxani & Whang, 1991).. From the perspective of organizational economics, Garicano's (2000) model of so-called Knowledge-Based Hierarchies has been particularly influential. Garicano (2000) conceptualizes organizations as hierarchical systems for efficient

information processing and problem solving. Core assumptions in the model are that knowledge is heterogeneous, that firms face problems that require solving, and that there are cost-tradeoffs that affect firms' optimal organizational structure. That is to say that employees and managers possess disparate expertise, and relevant skills are distributed across hierarchical levels. Employees address routine issues independently using their own knowledge, while complex, exceptional problems escalate to managers with greater expertise. Within this framework, decentralization, the delegation of decision-making authority to lower levels of the organizational hierarchy, emerges as a rational response to minimizing two key costs: information acquisition costs (e.g., training lower-level workers to handle more complex tasks) and communication costs (e.g., escalating unsolved problems to higher-level managers).

ICT plays a central role in this cost calculus where the model of Knowledge-Based Hierarchies offers a nuanced prediction. When ICT lowers information acquisition costs (by giving employees direct access to knowledge, databases, or analytics), it can enable decentralization by allowing lower-level workers to solve a broader set of problems independently. Conversely, when ICT lowers communication costs (by improving upward reporting, dashboards, or real-time supervision), it can reinforce centralization, as it becomes less costly for higher-level managers to remain directly involved in decision-making.

This potential for opposing effects implies that the consequences of ICT for decentralization are not uniform and depend on which frictions the technology alleviates most (Bloom et al. 2014). Empirical studies often emphasize ICT's decentralizing effects, particularly in situations where information acquisition appears important to firms. Acemoglu et al. (2007) find that firms that have a higher share of workers using computers and are in more IT (Information Technology) intensive industries are more likely to be decentralized. In addition, they find that firms that appear more in need of processing novel, non-public information (e.g., because they are closer to the technological frontier) are more decentralized.

Bresnahan et al. (2002) also report a strong positive correlation between firms' IT capital and decentralized work organization. In addition, they find that decentralization strengthens the positive effect of IT capital on productivity, suggesting that ICT can indeed shift the cost-calculus of decentralization vs. centralization. Wu et al. (2019) further find a synergy between decentralization and ICT in the area of innovation where the use of data analytics has a positive effect on innovation output but only when a firm is sufficiently decentralized.

Together, these studies suggest that ICT is a powerful tool facilitating distributed decision-making. In contrast, these studies do not provide evidence of ICT reinforcing central control on net. However, because we assess the overall effect of ICT rather than only information acquisition of early legacy systems or communication tools, we propose the following non-directional hypotheses:

Hypothesis (H0): Investment in ICT has no effect on the degree of organizational decentralization of decision-making authority.

Hypothesis (H1a): Investment in ICT increases the degree of organizational decentralization, delegating decision-making authority to lower hierarchical levels.

Hypothesis (H1b): Investment in ICT increases the degree of organizational centralization, shifting decision-making authority to higher hierarchical levels.

2.2. The Decentralizing Effect of Early-Generation ICT vs. Later-Generation ICT

While early ICT investments were associated with decentralization, the cost perspective of the Knowledge-Based Hierarchies model proposes that ICT is not a unidirectional force that uniformly empowers lower-level employees. The capacity of ICT to disseminate information downward is only one side of the coin. As digital technologies advance, they may lower communication costs and enable real-time data collection, algorithmic monitoring, and decision

enforcement. These features of ICT, in turn, would support centralized oversight, enabling the shift of power away from lower layers in the organizational hierarchy. This dual nature complicates the analysis of the effect of investing in ICT on firm (de)centralization. It seems that ICT can both distribute and consolidate authority, depending on the type of ICT adopted (communication-oriented technology or information-oriented technology), which is empirically supported by Bloom et al. (2014).

The key issue that studies of the ICT-decentralization relationship need to address is more general, however. This issue is the evolution of the kind of ICT that firms have been able to adopt. Acemoglu et al. (2007), for example, consider a simple measure of ICT, the use of computers, which likely exhibited much more interfirm variation in the 1990s than in the 2020s. Bloom et al. (2014) similarly use aggregated data for the period 2000-2006 concerning three specific, older-generation technologies: the presence of an intranet (proxying for communication technology) and the use of Enterprise Resource Planning (ERP; e.g., Oracle and SAP) and CAD/CAM techniques (both proxying for information technology). Although these technologies continue to be used, nowadays firms mostly invest in rather different types of ICT. More recent ICT investments are in such technologies as cloud computing platforms (e.g., AWS, Azure, Google Cloud), software-as-a-service (SaaS) applications, Artificial Intelligence (AI) and machine learning tools, and collaboration software. As a result, the (net) decentralizing effect of investing in ICT found in older data may not be present in data that are more recent (or vice versa). Comprehensive understanding of the ICT-decentralization relationship thus requires analysis of both older and newer data but also moving away from cross-sectional research designs towards longitudinal research designs that allow for considering the dynamic component of this relationship.

Considering the development of ICT in more detail, we find strong reason to think that over the last two decades or so ICT has evolved so that its organizational consequences have

been shifting towards a less decentralizing effect / more centralizing effect. Comparing older-generation and younger-generation ICT we observe developments and technological differences that seem to favor centralization a bit more. Three relevant developments that appear particularly relevant for organizational hierarchies and structures are as follows.

First, whereas late 1990s/early 2000s ICT expanded information access, late 2010s/early 2020s ICT has given rise to algorithmic decision-making. Earlier technologies such as intranets, email, and basic databases provided middle managers and employees with better information. This improved information access, in turn, enabled more autonomous decision-making at lower hierarchical levels. Modern technologies, in contrast, involve AI and machine learning systems that do not just provide information but can make decisions automatically. These algorithmic systems, in turn, tend to be controlled by senior management, thus removing decision-making authority from middle management and front-line employees (Baiocco et al., 2022; Ide & Talamas, 2024; Kellogg et al., 2020; Wood, 2021).

A second development with implications for the extent to which investing in ICT is decentralizing or centralizing is the rise of real-time monitoring and control. Early-generation ERP and similar systems provided periodic reports that senior management reviewed. Day-to-day operations, on the other hand, still required substantial localized autonomy or decision-making authority for lower-level managers and shop floor supervisors. Nowadays, however, smart sensors (Internet of Things) can collect lots of data and types of data that feed into real-time dashboards. Senior managers thus have immediate insight into ongoing operations and are able to do interventions that previously involved lower managers and delegation to local employees (Autor et al., 2024; Garicano & Wu, 2012).

Finally, we observe a shift from ICT systems that were tailored to the needs and demands of specific departments or business units to centralized, cloud-based systems that offer one-size-fits-all solutions. In the late 1990s/early 2000s, the benefits of unique, tailored systems

would still often outweigh the costs of developing such systems instead of relying on standardized (ERP) systems and processes. Cloud-based platforms and the like, however, are subject to strong economies of scale, increasing the relative costs of customization and reducing their economic feasibility. The power to decide on which system or platform to use thereby resides with upper management, meaning that they effectively set how all units or employees in the organization should work.

Meanwhile, there have of course also been developments in ICT that would still facilitate decentralization more than they facilitate centralization. A chief example is the advent of collaboration software such as Slack or Microsoft Teams. In their modern incarnations, these technologies greatly support flat communication structures (bypassing hierarchies), knowledge sharing, and peer-to-peer coordination, giving lower levels more means to get things done in the organization. In addition, blockchain technologies involve distributed ledgers and peer-to-peer transactions that are by their very nature decentralized (though their organizational use would typically be centralized).

Notwithstanding, we find that, on the whole, in the last 20 years or so ICT has moved from facilitating "informed delegation" (giving people better tools to make decisions) towards "algorithmic control" (having systems make decisions centrally and execute them locally). In short, technologies have evolved from supporting human judgment at multiple organizational levels to replacing human judgment with centralized algorithms and real-time oversight by high-level managers (Zuboff, 2019). We thus propose the following hypothesis:

Hypothesis 2 (H2): The decentralizing effect of investing in ICT has weakened over time.

3. DATA AND METHOD

3.1. Data

3.1.1. Data Source and Sample

Data for the analysis come from the Institute for Employment Research (IAB)'s Establishment Panel (IAB-BP; Bellmann et al. 2024). The IAB-BP surveys a stratified random sample of establishments across all industries and establishment size classes, covering firms with at least one employee subject to social security contributions, referenced to June 30 of each year. This panel provides a longitudinal survey of German establishments and contains representative annual data for West Germany since 1993 and for East Germany since 1996. As mentioned, it is one of the most comprehensive and longest-running employer surveys in the world and widely used (e.g., Arntz et al., 2025; Caldwell and Danieli., 2024; Gumpert et al., 2022). The panel includes some 15-16,000 establishments annually, representing about 1% of all German establishments employing at least one worker subject to social security contributions. Establishments that are included account for approximately 7% of all employment in Germany The establishments are drawn from a population of about 2 million German employers, making the panel uniquely suitable for studying organizational structures over time. The IAB-BP collects data through structured personal interviews with management-level personnel using questionnaire items.

For the analysis, we consider only establishments that have been included in the establishment survey multiple times, enabling us to control establishment fixed effects.[2] We further exclude establishments with missing data on the chief variables, which varies with model specification and alternative operationalization of the dependent and explanatory

[2] To allow for within-establishment variation and the inclusion of fixed effects, we restrict the sample to establishments observed in at least three distinct years for sufficient panel depth . We have checked and firms that have been included in the survey only once tend to resemble firms included multiple times.

variables in the analysis (hereafter: we use "establishment" and "firm" interchangeably). The outcome variable, downward shifting of responsibilities is observed from 1995 onward (and is a retrospective 2-year measure). We restrict our main explanatory variable as ICT investment to have up to three consecutive years of lagged data relative to the outcome variable. Because ICT investment is available beginning in 1993, usable lag structures are relative to decentralization outcomes beginning in 1998.

The main analyses cover establishments from period 1998–2021 and includes atleast 27,575 establishments and 83,668 observations (depending on model specifications). Furthermore, we retain distinct industry identifiers based on three business register vintages (1993–1999, 2000–2008, 2009–2021) when using industry fixed effects. Our data is unbalanced, as establishments may enter or exit the survey over time. To ensure comparability across specifications, the regressions are estimated on a consistent sample with uniform coverage of industries, years, and establishment characteristics.

Table A1 in the appendix presents an overview of the variables, a description of these variables and their measurement, and some descriptives.

Figure 1 complements this overview by illustrating the temporal evolution of ICT investment and decentralization from 2001 to 2021, shedding light on how the relationship between digital investment and organizational authority structures has changed over 20 years. In 2001, 43% of establishments reported ICT investments, a figure that rose sharply to 64% by 2021. In contrast, the prevalence of decentralized decision-making almost halved over the same period—from 15% in 1998 to just 7% in 2021 highlighting a divergence between technological investment and the distribution of decision-making authority within firms over time.

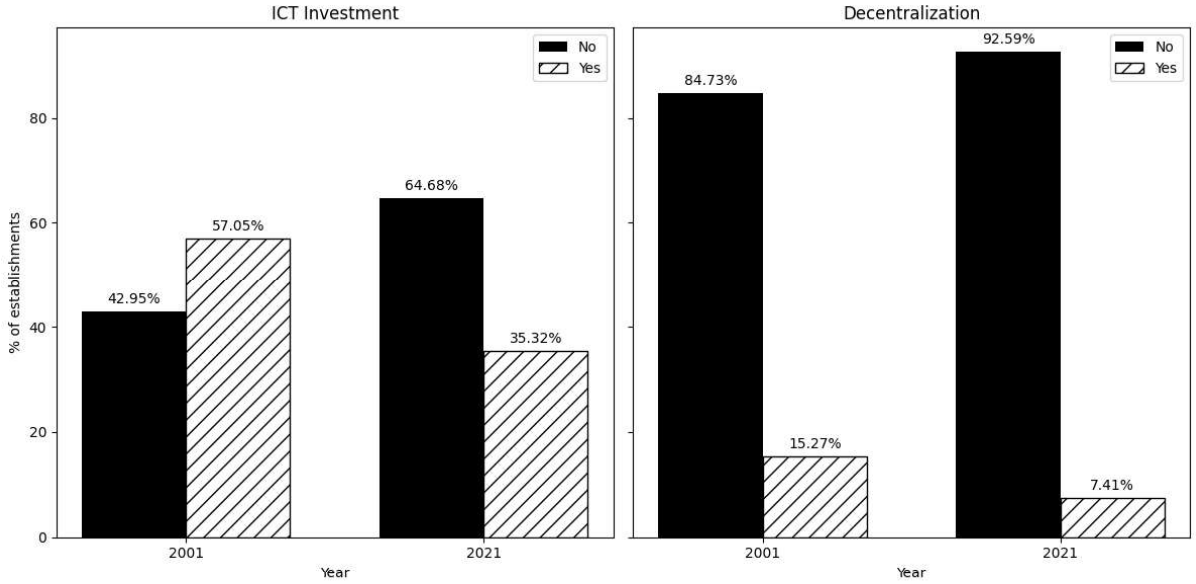


Figure 1: Changes in ICT investments and Decentralization (2001 vs 2021)

Notes: The bars display the percentage of establishments of the total establishments observed reporting either ICT investment in the previous business year or decentralized decision-making (i.e., downward delegation of authority) in 2001 and 2021, respectively. ICT investment equals 1 if the establishment reports operational investments in Electronic Data Processing (EDP) or Information and Communication Technologies (ICTs) in the previous business, and 0 otherwise, while decentralization is a binary indicator equal to 1 if decision-making responsibilities shifted downward within the organizational hierarchy (i.e., decentralization), and 0 otherwise.

3.1.2. Dependent Variable

The main measure of decentralization that we use derives from the establishment survey is a questionnaire item that asks establishment representatives about organizational changes that have been carried out at their establishment in the last two years. This item comes with a list of possible changes. One of these changes is the downward shifting of responsibilities and decisions. We create a dummy variable with value 1 if this downward shifting was mentioned and value 0 if not. This dummy variable captures whether decentralization of decision-making authority has taken place in the establishment or not. It is similar to the measure of decentralization considered by Bloom et al. (2014), which also concerns worker autonomy. The organizational changes item has not been included in all rounds of the survey but approximately

every 2/3 years from 1995 to 2021. Concretely, data on the decentralization measure is available for the following years: 1995, 1998, 2000, 2001, 2004, 2007, 2010, 2012, 2014, 2015, 2017, 2019, 2021.

To assess the robustness of the results, we also consider two alternative measures of decentralization based on the other survey items as the main decentralization measure. The first alternative measure concerns the introduction of teamwork / working groups with their own responsibilities as an organizational change. This dummy measure has value 1 if the introduction of such teamwork / working groups was mentioned as a potential organizational change in the last two years and value 0 if not. The second alternative measure concerns the introduction of units/departments carrying out their own cost and result calculations as a potential organizational change or not. Both measures consider the degree to which the establishment has taken decision-making authority away from upper management echelons to lower hierarchical levels in the organization. The first of these alternative measures is akin to the measure considered (Bresnahan et al., 2002) while the second is akin to the measure considered by Acemoglu et al. (2007). Data on these two alternative dependent variables are available for the same years as the main dependent.

3.1.3. Independent Variable

The independent variable concerns establishments' investment in ICT. We measure this variable using the survey item that asks establishment representatives about investments that the establishment made in the previous business year. The item lists four distinct areas of investment: (i) real estate and buildings; (ii) production facilities, plant and equipment, furnitures and fixtures; (iii) means of transport, transportation systems; and (iv) ICT. This item is available for all years, 1998-2021. However, from 2000 to 2001, there has been a change in wording concerning the area of ICT investment. Until 2000, investing in ICT was listed as

investment in the area “Communication technology, EDP,” where EDP stands for Electronic Data Processing. Since 2001 this same investment area was listed as ”EDP, information and communication technology.” Independent of whether information technology is explicitly mentioned next to EDP and communication technology, the three alternative investment areas have remained the same and clearly distinct from ICT (real estate and buildings; production facilities, plant and equipment, furnitures and fixtures; means of transport, transportation systems). Notwithstanding, this slight change may lead to non-random measurement error in the independent variable that can affect our estimates. To address this, all analyses include an interaction term between the measure of ICT investment and post 2000 dummy that we consider, this dummy variable has value 1 for data collected before 2001 and value 0 for data collected later.

In the empirical analysis, we consider different measures of ICT investment. Following prior cross-sectional studies, the main measure is a dummy variable that has value 1 if the firm invested in ICT in the year and value 0 otherwise. Because the dependent variable refers to decentralization in a previous business year, this means that we use the survey investment item from the year preceding the year of the decentralization measure. To wit, we link the decentralization measure included in the 1998 survey round, which refers to organization changes from 1996 to 1998, to the ICT investment measure based on the investment item included in the 1996 or earlier survey rounds. And so on for later years. This specific measure of investing in ICT has the advantage that it is consistent with and enables us to replicate extant cross-sectional studies of the ICT-decentralization relationship for our sample and time periods.

A second measure of ICT investment that we consider checking against reverse causality is a lagged explanatory variable. This variable is akin to the main measure described above, except that we exploit the longitudinal nature of the data. Concretely, we introduce a one-year lag to ensure that the ICT investment measure precedes the possible occurrence of

decentralization by at least one year. Ensuring this lag overcomes an important weakness of existing cross-sectional evidence, which is that it suffers reverse causality. Because of this advantage, these lagged measures are our preferred measures. Following the above example, we use this variable to link the decentralization measure based on the organizational changes item included in the 1998 survey round, which refers to 1996, to the ICT investment measure based on the investment item included in the 1995 survey round. And so on for later years.

Additionally, we consider a third measure that concerns ICT investment accumulated over the last two years. For this measure, we consider establishments' answers on the investment item over two consecutive years and add them up. The minimum value for this measure is thus 0, which means that the establishment did not invest in ICT in two consecutive years. Similarly, the maximum value is 2, which means that the establishment did invest in ICT in the two consecutive years under consideration. Finally, a value of 1 indicates that the establishment invested in ICT in one of the two consecutive years under consideration. The advantage of this measure is that it is less coarse than the two dummy variables, providing more information on how much an establishment has invested in ICT including the frequency of investment. Practically, we construct this variable by adding up the two variables described above. To wit, we link the decentralization measure based on the organizational changes item included in the 1998 survey round, which refers to 1996-1998, to two-year cumulative ICT investment based on the investment items included in the 1995 and 1994 survey rounds. And so on for later years.

Although our measure does not allow for continuous variation ICT (hardware) investments unlike some earlier studies which consider the Harte-Hanks Technology database(e.g. Acemoglu et al. 2007, Bloom et al. 2014, Bloom et al. 2012, Bresnahan et al. 2002, Garicano and Heaton 2010), it has several strengths. The Harte-Hanks Technology database primarily focuses on hardware infrastructure investments, neglecting a broader range of

technological advancements, and are constrained by shorter time spans and data from periods predominantly before the early 2000s. In contrast, our measure captures broader aspects of ICT adoption and a consistent perspective that spans a rich panel nearly three decades 1993–2021. This extended time coverage allows for a more comprehensive analysis of the long-term impact of ICT within organizations, balancing data availability and conceptual relevance.

3.1.4. Control Variables

A key feature of our data is that it is longitudinal, enabling us to add establishment fixed effects to control for unobserved time-invariant firm heterogeneity. However, we also include some basic (time-varying) control variables. These controls are firm size (measured as the log of the number of employees), industry fixed effects, and year fixed effects. As mentioned above, to address potential issues due to changes in the wording of the survey investment item, all models also include two additional variables. The first is a dummy variable that indicates whether data are collected before 2001 or not and the second an interaction term that includes this dummy and the measure of ICT investment.

To check the robustness of our main analysis, we also consider some additional control, variables. These added control variables are as follows: firm age, organizational form and skill intensity of the workplace based on extant literature[3] .

Meanwhile, a downside of adding these control variables is that they are not available for all the years in our sample. More importantly, some of these controls are likely "bad controls," which would bias our estimates (Angrist & Pischke, 2009; Cinelli et al., 2024).. In particular, some of these controls, for instance organizational form, are themselves outcomes of investing

[3] The firm age is the age of the firm relative to 2021 (end of the panel). In addition, consistent with prior literature we control for the skill-intensity of the workplace(Caroli & Van Reenen, 2001) by defining a variable that accounts for the percentage of the number of employees that are either unskilled or perform simple tasks. Finally, we also control for the organizational form, while prior literature has found that multinationals have a different organizational form (Bloom, Sadun, & Reenen, 2012), we control this through a binary construct of organizational complexity. Namely, whether the organization is simple (as an individual company or partnership) or not (by other complex forms including corporations, foundations etc.).

in ICT and decentralization (i.e., it is endogenous with regard to ICT investment, decentralization, or both). Hence, including these controls anyway would cause an overcontrol bias. We therefore consider these control variables only as a strict robustness check while the model with the basic controls is our preferred model.

Additionally, unlike prior cross-sectional studies, our use of establishment-level fixed effects allows us to account for firm heterogeneity directly. Including additional controls in this context risks inflating multicollinearity and obscuring the true relationship between ICT and decentralization. Third, this approach helps preserve larger sample consistency by minimizing attrition due to missing covariates[4].

3.2. Method

We seek to assess the effect of investing in ICT on the likelihood that an establishment has shifted decision-making authority to a lower level in the organization. As discussed in the data section, we make this assessment using different measures of ICT investment, particularly lagged and non-lagged ones. The basic empirical model that we estimate reads as follows:

$$\mathbf{D_{it}} = \boldsymbol{\alpha} + \sum_{k=0}^{2} \boldsymbol{\beta}_k(\mathbf{ICT_{it-k}}) + \boldsymbol{\gamma}\left(\mathbf{zfirm_size_{it-p}}\right) + \boldsymbol{\vartheta}(\mathbf{Year}_t) + \sum_{k=0}^{2} \boldsymbol{\delta}_k(\mathbf{Year_t} \times \mathbf{ICT_{it-k}}) + \boldsymbol{\rho_i} + \boldsymbol{\varphi}_j + \boldsymbol{\varepsilon_{it}} \quad (1)$$

Where:

(D_{it}) is a binary indicator equal to 1 if firm i experienced a downward shift in decision-making authority in year t, and 0 otherwise.

(ICT_{it-k}) indicates whether the firm invested in ICT in year $t-k$

[4] For robustness, we supplement the baseline model with aforementioned used controls—such as firm age, skill intensity, and organizational form—and find that the core results remain stable. These variables exert only marginal influence on the ICT-decentralization relationship, particularly once fixed effects are accounted for.

$(firm_size_{it-p})$ is the natural logarithm of firm size (employee count) at $t-p$ where p is 0 or 1; 0 if k is 0 and 1 otherwise, for values of k in ICT in year $t-k$

$(Year_t)$ are year indicators, 1 for the corresponding year and 0 otherwise (1993-2021).

ρ_i, φ_j and τ_t denote firm, industry, and year fixed effects.

ε_{it} is the random error term

H1 predicts that $\boldsymbol{\beta_k > 0}$, indicating that (cumulative) ICT investment increases the likelihood that an establishment shifts decision-making authority to a lower level. H2 predicts $\boldsymbol{\delta_k < 0}$, indicating that the decentralizing impact of (cumulative) ICT investment weakens over time.

In the analysis, we estimate different versions of Eq. 1. For example, to set the stage, we follow previous cross-sectional studies and estimate a simple model that excludes establishment fixed effects and in which ICT investment is neither lagged nor cumulative (aggregated over three years). For the main part of the analysis, however, we control establishment fixed effects and consider establishments' investment in ICT cumulated over the two years prior to the years for which we observe decentralization.

Additionally, for H2, we further test the model for structural break in the relationships and after testing for structural break around 2010, we define a Post2010 indicator, which is 1 when survey years 2010 and later, and 0 otherwise. Like the years indicator above we interact it with our primary explanatory variable (cumulative) ICT investments and test if the coefficient is significant and negative to provide support for H2.

As is common, in all analyses we estimate linear probability models(LPM) with heteroskedasticity- and autocorrelation-consistent (HAC) standard errors that are corrected for clustering at the establishment level.[5]

[5] We also test for consistency and check our results with conditional logistic regression models. For ease of exposition and interpretability, we use linear probability model(LPM) in our main analyses.

4. RESULTS

4.1. Baseline Results

4.1.1. Investing in ICT and Decentralization of Authority to Lower Levels

Table 1 presents results assessing the relationship between investing in ICT and decentralization of decision-making authority (H1). There are five models examining the relationship between ICT investment and the decentralization of decision-making authority. Model 1 is specified to resemble prior work that has studied the cross-sectional relationship between ICT investment and decentralization. In line with prior work, results indicate ICT investments are associated with decentralization within organizations. Namely, a firm investing in ICT has 8.7 percentage point increase in the likelihood of decentralization relative to when it is not investing in ICT Results for Model 2 indicate that the positive effect relationship is robust to controlling for establishment fixed effects. However, the coefficient for ICT investment is almost half compared to controlling for establishment fixed effects, 0.087 vs. 0.048. Hence, it seems that extant cross-sectional studies of the ICT-decentralization relationship suffer an upward bias due to omitted variables. That is, part of the cross-sectional relationship between ICT and decentralization appears spurious, reflecting differences in decentralization due to stable, non-time-varying (un)observed firm level factors that affect both investing in ICT and decentralization. Model 3 goes a step further, using the longitudinal nature of the data to check for temporal causality of making an ICT investment and decentralization occurring in the two years after. In this case, the coefficient is slightly smaller still directionally and statistically significant , 3.0 percentage points in Model 3 vs. 4.8 percentage points in Model 2. Models 4 and 5 present results using the alternative measure of ICT investment discussed in the data section, namely ICT investment cumulated over three years. Results indicate a strong relationship between decentralization and lagged and non-lagged ICT investment. Although not definitive proof, it seems likely that these results, particularly for Models 3 and 5, which include

establishment fixed effects and a lagged measure of ICT investment, present the causal effect of ICT on decentralization. Models without establishment fixed effects and using contemporaneous ICT measures are susceptible to simultaneity bias. For Models 3 and 5, however, endogeneity issues are less salient, and we cannot think of a plausible alternative explanation to account for the found relationship.

In the preferred models (3 and 5), We conclude that results support H1a, namely investing in ICT increases the likelihood that an organization decentralizes.

4.1.2. Time Variation in the Relationship Between ICT Investments and Decentralization

Figure 2 presents marginal effects of ICT-decentralization over time assessing whether there is a downward trend in the decentralizing effect of investing in ICT (H2). Table 2 presents the regression results for temporal variation in lagged cumulative measure of ICT investment Using the first year for which we observe decentralization from 2001 as the reference, we observe consistent results. Across all two previous business year(s) the ICT × Year interaction terms are negative and statistically significantly associated with decentralization at the 1% level, indicating that the decentralizing effect of ICT investments has declined in more recent years compared to earlier years and providing strong support for Hypothesis 2. Importantly, in Model 8 of Table 2, the cumulative investments of two concurrent years' ICT × Year interaction are much more significant and strongly negative in in magnitude, meaning that decentralization gains from repeated investments are eroded much more compared to one-off technology investments. This is apparent from Figure 3 which shows the predicted probabilities of decentralization for model 4, Table 2.

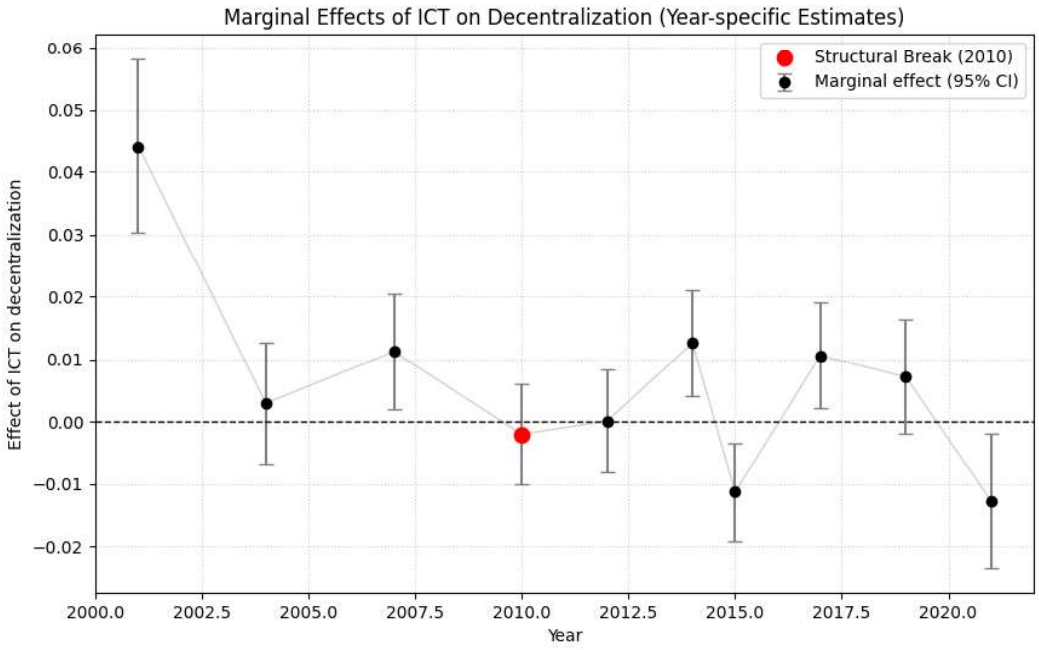


Figure 2: Marginal Effects of ICT on Decentralization over time

Notes: The figure displays year-specific marginal effects of ICT investment on decentralization, estimated from a model 6 of Table 2, fixed-effects regression with clustered standard errors. The black dot represents the marginal effect for each observed year, while the black line indicates the 95% confidence interval. The line is drawn through point estimates based on times of the survey years when decentralization is observed.

We also confirm this evidence using a continuous measure of year instead of dummies in Model 7. The direct effect of investing in ICT on decentralization is positive while the coefficient for lagged cumulative investment interacted with year is negative (and statistically significant at usual levels; Models 4 and 6 in Table 2). Further confirmation about the structural break in the relationship is apparent and comes from models that divide the sample into two periods, before 2010 and 2010 and after (Model 9 of Table 2). Results indicate that the decentralizing effect of investing in ICT has significantly changed and there is negative effect post 2009 with Post2010 × ICT interaction. We conclude that results support H2, the effect of investing in ICT on decentralization of decision-making authority has weakened over time.

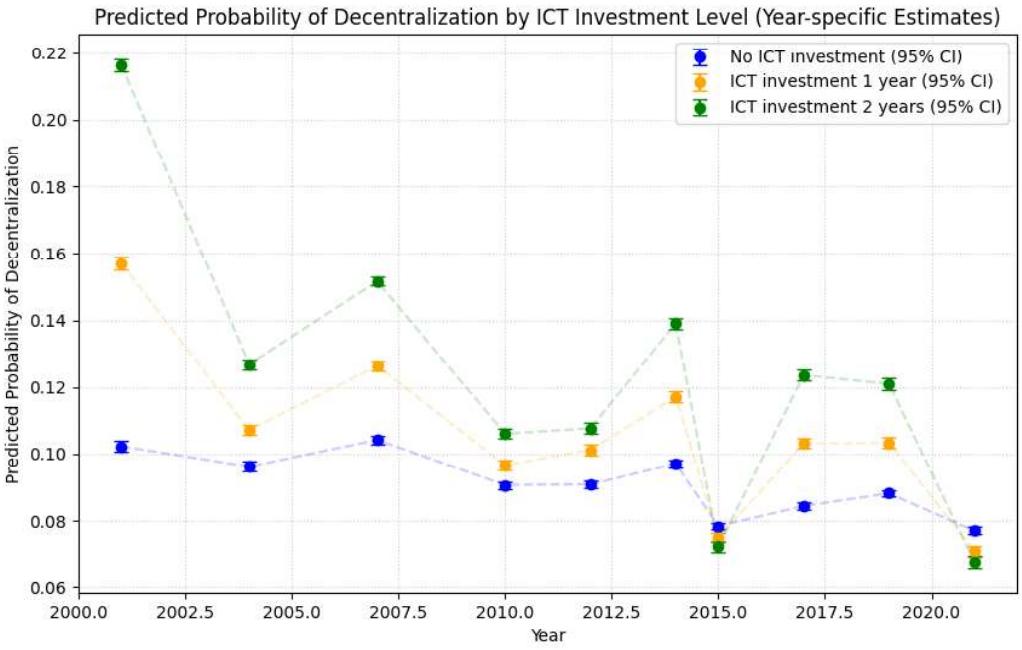


Figure 3: Predicted probabilities of decentralization across years

Note: This figure shows the predicted probability of decentralization across years for three ICT investment scenarios: no ICT investment (blue), ICT investment for one year (orange), and ICT investment for two years (green). Predictions are based on Model 8 of Table 2, controlling firm size, industry, and year fixed effects, with standard errors clustered at the firm level. The t 95% confidence intervals around the predicted means.

4.2. Robustness Checks

To ensure the robustness of our findings on the relationship between ICT investments and firm decentralization, we conduct several additional tests, including alternative constructs for decentralization, additional control variables, and an event-study design to address some of the endogeneity concerns.

Alternative Decentralization Constructs

We test the robustness of our results using two additional measures of decentralization, following established literature and find consistent results:

Units/Departments with Own Cost (Profit) Center Calculation: This construct, also

used by Acemoglu et al. (2007), captures decentralization by identifying units or departments within the firm that operate with independent cost or profit center calculations, reflecting greater (financial) decision-making autonomy.

Self-Managing Teams/(Team) Autonomy: Drawing on Bresnahan et al. (2002), this measure assesses decentralization through the presence of self-managing teams or the degree of team autonomy, indicating a shift in decision-making authority to lower levels.

Additional Control Variables

To account for potential confounding factors, as mentioned earlier we include the following (primary) and additional controls in our robustness checks:

- Firm Age: To capture the influence of organizational maturity on decentralization.
- Skill Intensity of Workers: To control workforce composition, which may affect the adoption and impact of ICT.
- Organizational (Legal) Form: To account for differences in governance structures that could influence decentralization outcomes.

Stacked Difference-in-Differences (DiD) Event-Study Design: While endogeneity concerns may still valid due to firm specific shocks, we provide causal evidence of the effect of firms' (first) ICT investments on organizational decentralization by employing a stacked difference-in-differences event-study design, following Bessen et al. (2025). This approach examines the decentralization effect of ICT investments by comparing firms before and after their first ICT adoption and creating cohorts around the first ICT investment event window (+/-4 years), We confirm that parallel pre-trends hold, ensuring the validity of the DiD framework and find that treated firms have a higher likelihood of decentralization compared to control firms, namely firms that never invest in ICT or invest in ICT later than the event window. The results from this design provide

robust evidence of (first) ICT investment impact on decentralization, reinforcing our findings for H1b.

These robustness tests collectively strengthen the reliability of our results, confirming that the decentralizing effect of ICT investments is consistent across alternative decentralization measures, additional controls, and mitigating potential endogeneity concerns.

5. Discussion

5.1. Findings and Contributions

Does ICT shift decision-making authority from managers to non-managerial employees, or does it reinforce managerial control? To provide a detailed answer to this question, we have considered three key issues in ICT-decentralization relationship: the role of unobserved time-invariant establishment characteristics, reversing causality between (de)centralization and investing in ICT, and temporal variation in ICT's decentralizing effect. The main findings of our comprehensive longitudinal analysis are as follows.

First, we find that investing in ICT leads firms to decentralize more, i.e., to shift decision-making authority to lower levels. We obtain this effect while including establishment fixed effects that address potential omitted variable bias and a lagged investment term that addresses the obvious form of potential reverse causality. Hence, although we do not provide definitive causal evidence, we cannot think of a plausible alternative explanation other than a causal effect of investing in ICT on the likelihood that an establishment decentralizes. Importantly, the attenuation of this relationship when establishment fixed effects are introduced suggests that earlier studies may have overstated the causal impact of ICT on decentralization. Much of the variation appears to be driven by stable, between-firm differences rather than within-firm organizational change. Second, we find that, compared to older ICT, recent ICT tools and systems increasingly foster managerial oversight and control, even though investing in ICT is still on net decentralizing. This finding derives from the result that ICT's

decentralizing effect has weakened significantly over the period studied, 1993-2021 with structural changes from 2010. As for the second finding, because of data limitations, we cannot unpack how firms go about adapting their organizational structures to the kind of ICT that they invest in. Similarly, we lack data on how the kind of ICT that establishments invested may have changed (e.g., from ERP and intranets in the late 1990s to cloud computing and AI and machine learning tools in the late 2010s and early 2020s). At the same time, we do know that ICT has changed over the years, and it seems plausible that this changing nature is driving the observed weakening of ICT's decentralizing effect. Lastly, our third contribution, related to second, is about the frequency of investments and how they can shift decision-making authority. Cumulative and concurrent ICT investments have stronger (re)centralizing overtime implying organizational restructuring upwards is compounded through ICT investments.

Decentralization and delegation are defining features of organizations and have long been linked to various characteristics of ICT (Brynjolfsson and McAfee 2014, Hoos 1960, Leavitt and Whisler 1958, Zuboff 1988). Tracing back several decades, empirical evidence on the question whether ICT leads to centralization or decentralization has long been ambiguous (George and King, 1991; Wyner and Malone, 1996). Recent work suggests that the answer to this question partly depends on how ICT is used or what type of ICT is adopted: ICT that facilitates information acquisition can enable decentralization whereas ICT that facilitates communication can reinforce centralization (Bloom et al. 2014; Garicano 2000). Our findings add further richness to such insights on the ICT-decentralization relationship. In particular, using panel data, we can overcome key limitations of the cross-sectional evidence presented by extant studies by underscoring the importance of dynamics, use and frequency of ICT investments.

An important empirical contribution of this paper is that it provides systematic evidence on the relationship between ICT investment and the delegation of decision-making

authority to lower organizational levels. Using longitudinal data, we go beyond prior cross-sectional studies and demonstrate how changes in ICT are associated with subsequent changes in organizational decentralization over time. This allows us to identify the net organizational effect of ICT rather than capturing only static correlations or early legacy systems.

Two further contributions concern insights into the dynamic nature of the ICT–decentralization relationship. First, we show that ICT does not exert a uniform or monotonic effect on organizational structure; instead, its impact evolves over time as technologies are adopted, integrated, and routinized within organizational processes. Second, our results reveal a non-linear pattern: while ICT is initially associated with increased delegation of decision-making authority to lower hierarchical levels, this decentralizing effect is partially reversed over time, as decision rights are subsequently re-centralized. This demonstrates that ICT simultaneously enables both decentralization and renewed central control, depending on the stage of technological integration.

Theoretically, this paper contributes by reconciling competing views in the literature by incorporating the temporal dimension. While ICT has long been argued to facilitate both central control and distributed decision-making, empirical evidence on how these effects unfold over time has remained limited and fragmented. By explicitly modeling both the direction and the temporal dynamics of the ICT–decentralization relationship, our findings clarify when and how ICT functions as an organizational design mechanism rather than merely an operational tool.

5.2. Limitations and Future Research

Our study has several limitations that open avenues for future research. First, the available measure of ICT investment is necessarily coarse. It only records whether an establishment has invested in ICT but not how much (e.g., as a share of total investment). Similarly, we are unable

to know which kind of ICT the establishment invested in, an intranet, an ERP system, or collaboration softwares. For one of the robustness checks, we considered a measure of cumulative ICT investment over two years. This measure partly addresses this limitation, offering a more fine-grained way of capturing the extent to which establishments have invested in ICT. Still, from prior work, we know that the organizational consequences of investing in ICT likely vary with the kind of ICT that is adopted or implemented. As is, our panel data are too coarse to distinguish such heterogeneous effects of ICT. Hence, a longitudinal disentanglement of the effects of specific ICT types remains a key direction for future research, although one that comes with challenging data requirements.

Second, although we mitigate simultaneity and establishment-specific time-invariant endogeneity concerns using measures of lagged ICT investment and establishment fixed effects, unobserved shocks that jointly influence both ICT investment and decentralization cannot be entirely ruled out. As stated above, we cannot think of a plausible alternative explanation for our results other than a causal effect of investing in ICT on decentralization and further test through event-study difference-in-difference framework. Still, future work may offer stronger identification strategies such as regional variation in technological that provide further validation for the causal factors driving the observed but evolving relationship between investing in ICT and decentralization.

Finally, while we document structural changes in internal authority allocation, we do not observe downstream implications for worker outcomes or firm performance. The impact of ICT-induced decentralization on productivity, employee autonomy, and organizational inequality remains salient as firms increasingly adopt frontier technologies with possibilities of algorithmic management, remote monitoring, and platform-based coordination tools that may reshape how control is exercised and distributed within firms.

6. Conclusion

This study provides novel evidence on the evolving relationship between information and communication technologies (ICT) and the decentralization of decision-making authority within firms. Because ICT reshapes the organization and control of economic activities and value creation, firms face a fundamental transformation, changing core organizational features and the essential nature of the workplace. Decentralization is a key feature of how firms are organized but ICT's effect on delegation and downward shifting of authority is theoretically ambiguous. Some types of ICT may pull organizations toward concentrated control but others to less centralized decision-making. This question is thus in need of empirical evidence, particularly evidence that is not subject to the limitations suffered by the cross-sectional research designs of extant studies. Using German annual establishment-level panel data covering the years 1993-2021, our comprehensive longitudinal analysis indicates a strong positive relationship between investing in ICT and decentralization. We find this relationship while controlling time-invariant unobserved establishment characteristics and using a lagged measure of ICT investment. Hence, investing in ICT appears to have a causal effect on shifting authority to lower levels. Importantly, and completely absent in the extant literature, ICT's apparent decentralizing effect is not consistent over time but has gradually weakened. It thus seems that technologies that are more recent facilitate centralized oversight more than they do downward delegation, reflecting a shift in the functional role of ICT tools and systems from enabling autonomy to enforcing control. Chief avenue for future research is to link the dynamic relationship between ICT and decentralization to empirical measures of the changing nature of ICT as it is implemented and used by firms.

APPENDIX

Table 1. (Cumulated and Lagged) ICT Investments and Firm Decentralization

Dependent variable = Decision-making authority delegated to lower levels (1=yes)	Non-lagged, non-cumulative ICT		Lagged, non-cumulative ICT	Non-lagged, cumulative ICT	Lagged, cumulative ICT
	Model 1	Model 2	Model 3	Model 4	Model 5
ICT investment, t-2, relative to survey year (1=yes)	0.0868 (0.007) [p=0.000]	0.0478 (0.008) [p=0.000]	-	-	-
ICT investment, t-3, relative to survey year (1=yes)	-	-	0.0302 (0.008) [p=0.000]	-	-
Cumulative ICT investments, t-3 and t-2, relative to survey year (0,1,2)	-	-	-	0.0337 (0.006) [p=0.000]	-
Cumulative ICT investments, t-4 and t-3, relative to survey year (0,1,2)	-	-	-	-	0.0243 (0.006) [p=0.000]
Post2000	-0.205 (0.027) [p=0.000]	-0.2161 (0.045) [p=0.000]	-0.2067 (0.045) [p=0.000]	-1.1634 (0.081) [p=0.045]	-0.1657 (0.082) [p=0.042]
ICT investment=0 × Post2000=1	0.0493 (0.007) [p=0.000]	0.0372 (0.008) [p=0.000]	0.0274 (0.008) [p=0.001]	-0.0243 (0.006) [p=0.000]	-0.0205 (0.006) [p=0.001]
Firm size (ln) (t-2 or t-3, relative to survey year)	0.0286 (0.001) [p=0.000]	0.0134 (0.004) [p=0.000]	0.0080 (0.003) [p=0.020]	0.0112 (0.004) [p=0.004]	0.0112 (0.004) [p=0.004]
Industry effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
No. of observations	113,844	113,844	113,844	91,042	91,042
No. of establishment	36,660	36,660	36,660	28,750	28,750
R2 within	0.0145	0.0178	0.0171	0.0135	0.0130
R2 between	0.116	0.0610	0.0436	0.0511	0.0448
R2 overall	0.0758	0.0426	0.0306	0.0331	0.0289

Notes: Table reports marginal effects.*. Standard errors (in parentheses) and p-values (in square brackets) are clustered at the level of establishments. Decentralization refers to decision-making authority delegated to lower levels in the last two years, relative to survey year.

Table 2. Temporal variation in the Relationship Between ICT Investments and Firm Decentralization

Dependent = Decision-making authority delegated to lower levels (1=yes)	Model 6	7	8	9
Cumulative ICT investments two years before	0.0442 (0.007) [p=0.000]	2.2160 (0.641) [p=0.001]	-	0.0145 (0.004) [p=0.000]
Cumulative ICT investment two years before = 1			0.0263 (0.014) [p=0.063]	
Cumulative ICT investment two years before = 2			0.0879 (0.014) [p=0.000]	
Cumulative ICT investments two years before x year dummies	Yes*	-	Yes*	No
Cumulative ICT investments two years before x year	-	-0.0011 (0.0003) [p=0.001]	-	No
post2010				-0.0948 (0.048) [p=0.046]
Post2010 x Cumulative ICT investments two years before				-0.0132 (0.004) [p=0.001]
Firm size (ln)	0.0097 (0.004) [p=0.016]	0.0094 (0.004) [p=0.019]	0.030 (0.007) [p=0.000]	0.028 (0.007) [p=0.000]
Standard controls	Yes	Yes	Yes	Yes
No. of observations	83,668	83,668	83,668	83,668
No. of establishment	27,575	27,575	27,575	27,575
R2 within	0.0093	0.0079	0.0095	0.0079
R2 between	0.0214	0.0204	0.0219	0.0201
R2 overall	0.0155	0.0145	0.0160	0.0141

Notes: Table reports marginal effects and sample starts from 2001. Standard errors (in parentheses) and p-values (in square brackets) are clustered at the level of establishments. *To improve the readability of the table, we report a selection of coefficients, but complete results are available on request.

Table A1. Overview and descriptive statistics of key variables

Variable	Definition/description	Obs.	Mean and standard deviation
Downward shifting of responsibilities and decisions/Worker Autonomy	Dummy variable that indicates whether the establishment reports that a downward shifting of responsibilities and decisions has occurred within their establishment/office in the past two years (=1), or not (=0). The underlying measure of worker autonomy is based on the item asking respondents: *"Has one or more of the following organizational changes been carried out within your establishment/office in the last two years?"* with one of the listed changes being *"Downward shifting of responsibilities and decisions."* This dummy variable captures the presence of decentralized decision-making structures that may enhance individual autonomy at the workplace.	91,315	μ=11.36% SD=31.73%
Self-managing Teams/Team Autonomy	Dummy variable that indicates whether the establishment reports the introduction of team work or working groups with their own responsibilities has occurred within their establishment/office in the past two years (=1), or not (=0). The underlying measure of team autonomy is based on the item asking respondents: *"Has one or more of the following organizational changes been*	91,315	μ=5.80% SD=23.38%

	carried out within your establishment/office in the last two years?" with one of the listed changes being *"Introduction of team work/working groups with their own responsibilities."* This variable serves as an alternative to the main dependent variable and captures decentralized, team-level decision-making structures within the workplace.		
Responsibility Centers - Cost or Profit	Dummy variable that indicates whether the establishment reports that the introduction of units or departments carrying out their own cost and result calculations has occurred within their establishment/office in the past two years (=1), or not (=0). The underlying measure of departmental autonomy is based on the item asking respondents: *"Has one or more of the following organizational changes been carried out within your establishment/office in the last two years?"* with one of the listed changes being *"Introduction of units/departments carrying out their own cost and result calculations."* This variable serves as a further alternative to the main dependent variable and captures decentralized financial and performance accountability at the departmental level.	91,315	μ=4.64% SD=21.04%
Lagged Cumulative ICT investment	Ordinal variable ranging from 0 to 2, constructed as the sum of two binary indicators capturing whether an establishment invested in information and communication technology (ICT) in each of the two years preceding the	91,315	μ=0.88 SD=0.86

	decentralization measure survey (i.e., *t-3 and , t-4*). The underlying measure is based on responses to the item: *"Did your establishment invest in one or more of the following areas in the last business year of (YYYY-1)?"* with one of the listed areas being *"EDP, information and communication technology."* A value of 0 indicates no ICT investment in any of the two years, while a value of 2 reflects investment across the two years. This variable captures the intensity and continuity of ICT investment and serves as the main independent variable in the analysis. Importantly, the investment periods precede the reference period for the dependent variables, which measure organizational changes (e.g., decentralization) occurring within the last two years. This temporal structure supports a causal interpretation by ensuring that ICT investment is measured prior to the observed changes in workplace autonomy.		
Lagged ICT investment	Dummy variable indicating whether an establishment invested in information and communication technology (ICT) in the business year corresponding to $t-3$, i.e., three years prior to the decentralisation reference period (1 = yes, 0 = no). This variable is constructed from survey responses to the item: *"Did your establishment invest in one or more of the following areas in the last business year of (YYYY-1)?"* with one of the listed areas being *"EDP, information and communication*	91,315	μ=43.42% SD=49.57%

	technology." This variable serves as a baseline indicator of ICT investment and is used in alternative specifications of the main		
ICT investment	Dummy variable indicating whether an establishment invested in information and communication technology (ICT) during the same reference period as the decentralization measures (1 = yes, 0 = no). This variable is constructed to align with the timing of the decentralization outcomes and is based on responses to the item: *"Did your establishment invest in one or more of the following areas in the last business year of (YYYY-1)?"* with one of the listed areas being *"EDP, information and communication technology."* This contemporaneous measure is used co-occurrence between ICT investment and decentralization, and is used in alternative specifications of the main independent variable.	91,315	μ=43.07% SD=49.52%
Industry	Categorical variable indicating the sector in which the establishment operates, based on the 2-digit industry classification system maintained by the Federal Employment Agency. The variable is constructed from responses to the item: *"According to the establishment identification number registered with the Federal Employment Agency, this establishment was assigned to the following industry. Is this still up-to-date?"* If not, respondents are asked to update the classification using a provided industry table. This variable captures the economic	91,315	N/A More frequent industries are: Human Health (2009 rev); Other services (2000 rev) Economic,

	environment and sectoral context of the establishment, which may influence decentralisation patterns, ICT adoption, and organisational structure. It is included as baseline control in all model specifications to account for industry-level heterogeneity.		scientific and self-employed services (1993 rev)
Firm Size	Continuous variable constructed as the natural logarithm of the total number of employees, based on responses to the item: *"Please indicate how the total number of employees on 30 June (YYYY–1) of the previous business year."* Since decentralisation outcomes are measured at t–2, firm size is taken from t–3 in the preferred model to ensure temporal separation. The log transformation helps normalize the distribution and allows for proportional interpretation in regression models. Theoretically, firm size captures organisational scale, which may influence the capacity for decentralisation, managerial layering, and responsiveness to technological change	91,193	μ=3.16 SD=1.85

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