Information technology, organizational change and firm productivity: A panel study of complementarity effects and clustering patterns in Manufacturing and Services

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Explanation of symbols

.	= data not available
*	= provisional figure
**	= revised provisional figure
x	= publication prohibited (confidential figure)
–	= nil or less than half of unit concerned
–	= (between two figures) inclusive
0 (0,0)	= less than half of unit concerned
blank	= not applicable
2010–2011	= 2010 to 2011 inclusive
2010/2011	= average of 2010 up to and including 2011
2010/'11	= crop year, financial year, school year etc. beginning in 2010 and ending in 2011
2008/'09–2010/'11	= crop year, financial year, etc. 2008/'09 to 2010/'11 inclusive

Due to rounding, some totals may not correspond with the sum of the separate figures.

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Information Technology, Organizational Change and Firm Productivity: A Panel Study of Complementarity Effects and Clustering Patterns in Manufacturing and Services

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Abstract.

Organizational complementarities are an essential factor in the process of creating business value from information technology (IT) investments. Organizational change (OC) is an important complementarity. This paper investigates complementarities between IT capital and OC initiatives of the firm. It analyzes the productivity impact of different clusters of IT and OC in the manufacturing and services sectors of the economy. Three dimensions of OC are studied: process, structure, and boundary changes. Two distinct econometric approaches are applied to a unique and detailed sample of 32,619 firm-level observations in the Netherlands for the period 1994-2006. The results reveal that the productivity effect of IT significantly increases when technology investments are accompanied by relevant organizational changes. The observed complementarity effects between IT and OC are stronger for services than for manufacturing firms. The effects become stronger if different types of change are combined with each other and form clusters. In contrast to IT capital, non-IT capital and OC exhibit a substitutability relationship. As to another finding of the research, IT seems to play a dual role with respect to change: generating or stimulating it and complementing or supporting it. The first role is more dominant among manufacturing, while the second is among services firms.

Keywords: Information Technology, Organizational Change, Firm Productivity, Complementarities, Clusters, Manufacturing, Services.

1. Introduction

The productivity paradox of information technology (IT) has been the subject of a heated debate among economists, management scientists, and IT business value scholars over the two last decades (Brynjolfsson 1993, Triplett 1999). At the firm-level, the debate was concerned with a “what question”: what is the effect of IT investment on firm productivity? Since mid-1990s, researchers started to add another dimension to the inquiry by asking: how does IT affect firm performance? This “how question” is the central theme of research that promotes disaggregated, process-oriented models of IT value creation (Barua et al. 1995, Kelley 1994). The evidence reported so far in the literature provides insights into how IT contributes to organizational performance (Bartel et al. 2007, Bharadwaj et al. 1999, Brynjolfsson and Hitt 1996, Melville et al. 2004, Sircar and Choi 2009).

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Since the beginning of the 21st century, another relevant research question was raised: why do some firms reap substantial benefits from their IT investments while others don't? The *why* aspect concerns the availability and quality of organizational complementarities that enable or facilitate a firm to benefit more from its IT investment (Bharadwaj et al. 2007, Bresnahan et al. 2002, Brynjolfsson and Hitt 2000, Devaraj and Kohli 2003). Activities of firms do not act independently but interact with each other and constitute systems or clusters of tightly coupled and interconnected practices (Ichniowski et al. 1997, Levinthal 1997). Complementary resources jointly affect organizational performance and lead to competitive advantage (Brynjolfsson et al. 2002, Milgrom and Roberts 1995, Rivkin 2000). Misperceived interactions can be very costly for firms (Siggelkow 2002).

Complementarities exist if the total value added by combining two or more economic factors in a production system exceeds the value that would have been otherwise generated through these factors in isolation (Milgrom and Roberts 1990). In the scarce empirical research on complementarities between information systems (IS) and organizational practices, a few specific areas have received attention. Practices that aim at development of human capital, internal organization of the work and design of compensation systems account for the majority of these studies (Arvanitis 2005, Black and Lynch 2001, Bresnahan et al. 2002, Hitt and Brynjolfsson 1997). Much less attention has been, though, paid to organizational change (OC) (Ennen and Richter 2010, Giuri et al. 2008). Moreover, the focus in available studies has been the firm's internal organization, leaving changes in the external relations of the firm (due to IT use) an under-researched phenomenon.

This paper contributes to the literature in two ways. First, it empirically assesses the impact of complementarities and clusters between IT and OC on firm productivity. The paper broadens the concept of OC by incorporating boundary changes. In contrast to common conceptualizations of OC in the literature, the present study pays special attention to external developments in firm boundaries and its relations with external actors, taking into account the evidence on boundary spanning effects of IT systems (Hitt 1999, Pickering and King 1995, Sahaym et al. 2007, Zammuto et al. 2007). Furthermore, the paper distinguishes between manufacturing and services firms, which are expected to reveal different degrees of complementarity and patterns of clustering between IT and OC. This is in line with the general argument that complementarities between technological and non-technological aspects of the firm and patterns of organizational change are influenced (if not determined) by the nature of firm processes and outputs. Second, it proposes a new method to model complementarities between IT and OC such that enabling effects of IT are also accounted for in addition to its complementarity effects. When modeling complementarities is concerned, this method is an attempt to incorporate endogeneity or simultaneity of organizational change, which is a serious concern in the existing literature.

The empirical analysis is based on a unique and detailed dataset of 32,619 firm-level observations in the Netherlands over the period 1994-2006. The results are robust with respect to model specifications and parameter values that were used to build the research constructs. The findings indicate that strong complementarity exists between IT assets and change initiatives of the firm.

Similar complementarities are not found when conventional types of capital, instead of IT capital, are considered. We observe that complementarities are stronger when IT investments are combined with multiple types of organizational change at the same time. This point to potential interrelations among different types of OC. Comparing different industries reveals that services firms, in general, enjoy stronger complementary effects than manufacturing firms do. Furthermore, the findings witness two different change-related roles for IT. In manufacturing sectors, IT is found to be mainly a driver or initiator of change, while in services sectors it primarily supports or complements change.

Section 2 reviews the literature, develops the theoretical and empirical background of the research and formulates the hypotheses. In section 3, empirical models are developed and econometric methods are presented. In section 4, we describe the data and construction of variables. Section 5 reports the regression results. Reflection on the hypotheses by interpreting the results is found in section 6. Section 7 concludes the paper and identifies avenues for future research.

2. Theoretical and Empirical Background and Hypothesis Development

2.1. Dimensions of organizational change

Organizational change is a concept that covers three primary dimensions (Armbruster et al. 2008, Whittington et al. 1999): changes in organizational 1) processes (OCP), 2) structures (OCS), and 3) boundaries (OCB). Process changes are modifications of the internal routines, production processes, service/distribution methods, human resource management, communications, operations and support activities of the firm. Among others, business process re-engineering (Hammer and Champy 1993), quality circles and total quality management (Lawler et al. 1998, Zell 1997), lean production, just-in-time manufacturing (Shah and Ward 2007, White et al. 1999) and knowledge management (Alavi and Leidner 2001) lead to process changes.

Structure changes reflect modification of the structural elements or functional divisions of the organization due to reorganization efforts, introduction of new management methods or significant changes in strategy. Examples include newforms of organizing the work such as delayering of hierarchies and decentralization of authority (Geroski and Gregg 1994, Zeffane 1992), flexible, federal and cellular forms of organization (Bahrami 1992, Handy 1992, Miles et al. 1997), and N-form corporation (Hedlund 1994).

Boundary changes denote significant reforms in the relations of the firm with other organizations such as public institutes, customers, suppliers, competitors or business partners. These changes transcend the formal boundaries of the firm and manifest themselves in, for instance, boundaryless and disaggregated corporation (Devanna and Tichy 1990, Zenger and Hesterly 1997), hypertext organization (Nonaka and Takeuchi 1995), increased reliance on outsourcing, subcontracting and joint R&D collaboration (van Beers and Zand 2010, Wittington 1991), formation of strategic alliances and joint ventures (Gulati et.al. 2009, Merchant and Schendel 2000), and development of new sales/marketing channels (e.g. franchisees, call centers and internet portals).

2.2. Complementarities as a theory of organizational change

The theory of complementarities is an extension of the configurational theory, which has evolved from the contingency theory. The contingency theory (Fiedler 1964, Kast and Rosenzweig 1973, Otley 1980) considers "fit" as an essential element in designing the organization and improving its performance. In this view, there must be a certain degree of fit or match between practices and strategies of the firm in order to yield optimal results and attain corporate objectives. The contingency theory adopts a reductionist view by characterizing the organization as a set of loosely coupled elements. On the opposite, the configurational theory adopts an aggregated view of the organization (Miller 1987 and 1996, Mintzberg 1979). From this perspective, organizations are composed of tightly interdependent and mutually supportive elements such that the importance of each element can be best understood by making reference to the whole configuration (Miller and Friesen 1984).

The complementarities line of thought originates from the work of Milgrom, Roberts and their co-authors in early 1990s (Milgrom and Roberts 1990, 1994 and 1995, Milgrom et al. 1991). It is further advanced by, among others, Amit and Schoemaker (1993), Brynjolfsson and Mendelson (1993) and Radner (1993). Compared with the configurational theory, the theory of complementarities conceives the dynamics of organizational transformation a more complex phenomenon such that changing only a few of the system elements to their optimal values may not generate the benefits that can be achieved through a fully coordinated move or may even result in negative payoffs (Milgrom and Roberts 1995). This suggests that a partial or piecemeal implementation of organizational change might lead to worse outcomes, compared to the unchanged status quo. Moreover, the complementarities perspective systematically investigates the contribution of individual elements to performance of the whole, while the configurational theory treats configurations as a black box. This improvement is worthwhile as practices might reveal a positive contribution to performance when they are coupled with their complements whereas their isolated effects might be negative or neutral (see e.g. Ichniowski et al. 1997).

2.3. Empirical studies of organizational complementarities

Milgrom and Roberts (1990) adopted the notion of supermodularity as a formal approach for modeling and testing complementarities, which gave rise to a number of empirical publications on the topic of complementarities since the second half of 1990s (Ennen and Richter 2010). Some of the papers on organizational complementarities focus on the interaction between IT and non-IT (NIT) resources of the firm. The general idea is that IT resources are embedded and bundled together with non-IT resources. When it comes to the choice of specific non-IT resources, most of studies focus on (1) the skill and education level of the workforce and related human resource management practices (like training) and/or (2) the design of incentive/compensation systems and workplace organization (like teamwork and multitasking).[1]

A few other non-IT resources have also received attention in the literature. Based on data from 126 American manufacturers, Bharadwaj et al. (2007) report complementarity between IS capability of the firm and its interfunctional and interorganizational coordination mechanisms, manifested in marketing, manufacturing and supply chain processes. Their results indicate that these complementarity effects are significant predictors of manufacturing performance. Using data from 147 US firms from 1999 to 2002, Aral and Weill (2007) demonstrate that firms derive additional value from their IT investments through a mutually reinforcing system of organizational capabilities that are built on complementary competencies and routines (including technical, business and end-user skills, management quality, culture of IT use, and digital/internet transactions capability). In a similar attempt, Jeffers et al. (2008) rely on a sample of 64 third-party logistics firms and find that IT assets can alter the impact of non-IT resources and managerial capabilities (i.e. open communication culture and business work practices) on process performance of the firm. On the basis of a sample of 117 firms, the payoff to IT investments is also found to be greater for firms with higher levels of (related) diversification (Chari et al. 2008).

Complementarities between IT assets of the firm and its OC efforts that capture different aspects of change is an under-researched topic. Among the few existing studies, Giuri et al. (2008) use a panel of 680 small and medium Italian manufacturers during 1995-2003. Their results show that full complementarity among IT, human capital, and organizational change does not apply to small and medium enterprises. Yet, they found evidence of complementarity between employee skills and organizational change. Similarly, using a survey of 1,496 French manufacturing firms in 1993, Greenan (2003) reports a positive correlation between technological change (i.e. adoption of computer-aided systems) and reorganizations (e.g. delayering and use of autonomous workteams).

2.4. Hypothesis development

Three hypotheses are developed. Each hypothesis addresses the impact of complementarity between one of the three primary dimensions of organizational change- process, structure and boundary changes- and IT assets, on a firm's labor productivity. Figure 1 presents these hypotheses in the context of a conceptual model. As shown in the figure, we conceptualize the model such that the total effect of IT and OC on firm performance consists of an interactive part, which is the main subject of inquiry in this research, and a non-interactive part. Effects of IT and OC (arrow 1 and 2) partly complement each other (arrow 3)

[1] The notions of skill-biased technical change (SBTC) and skill-biased organizational change (SBOC) are at the center of these two streams of research. See Arvanitis (2005), Black and Lynch (2001), Bresnahan et al. (2002), Caroli and Van Reenen (2001) and Piva et al. (2005) for more discussions.

when affecting firm performance while the remaining parts affect performance directly (arrow 4 and 5).

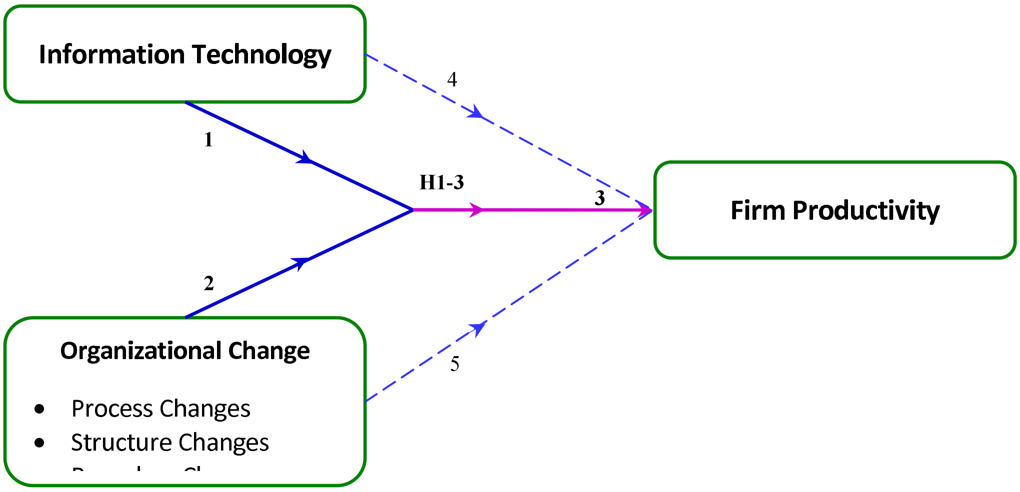

Figure 1: Conceptual Model and Research Hypotheses

2.4.1. Information technology and process changes of the firm

IT spawns process innovations like business process re-engineering (BPR), total quality management (TQM), just-in-time production (JIT), and lean manufacturing (Davenport 1993, Martinsons 1995). The new forms of production processes and organizational practices benefit from the increasing communication, computation, and automation capacity of IT as well as its significant coordination, integration, and transformation capability (Bharadwaj et al. 2007, Zammuto et al. 2007). In connection to IT-based process transformation, higher levels of IT infrastructure capabilities affect efficiency and success of business process redesign (BPR) positively (Broadbent et al. 1999). There is also evidence for significant intermediation of process innovation in creating business value from IT adoption (Koellinger 2008, Zand and van Beers 2010). Another important aspect of process changes concerns knowledge management (KM) initiatives of the firm. Appropriate IT deployment should be combined and then aligned with KM policies/practices of the firm in order to ensure effective knowledge creation, sharing and utilization that further lead to improved organizational performance (Choi et al. 2008, Zack 1999).

The distinctive capabilities of IT, on the one hand, and information-, communication-, and coordination-intensive features of particular practices such as new forms of production/servicing and KM initiatives of the firm, on the other hand, re-inforce each other's individual effects on firm performance. Application of IT resources to specific business processes of a firm may result in realization of their full potential value and thus may lead to generation of process-level advantages, even if there are no other sources of competitive advantage involved in these processes per se (Jeffers et al. 2008, Zamutto et al. 2007). The above considerations lead to Hypothesis 1 (H1):

H1: Information technology assets and changes in organizational processes of the firm due to knowledge management initiatives, introduction of new production methods, business processes or support activities or significant alteration of them function as complements in explaining firm performance.

2.4.2. Information technology and structure changes of the firm

Hitt and Brynjolfsson (1997) argue that IT leads to breaking down the hierarchical structure of the firm in favor of a system of decentralized authority and related practices. IT makes it easier and cheaper to generate, process and disseminate relevant information and knowledge to different layers of the organization where it is needed (Fulk and DeSanctis 1995, Leonardi 2007). IT makes it also possible and more convenient to exert relevant monitoring and control over the operations of lower level agents without a need for restrictive command-and-control mechanisms (Zammuto et al. 2007, Zuboff 1988). Moreover, IT adoption spurs more flexible, flat and integrated forms of labor division such as cross-functional teams and project-based forms of organization, in place of rigid traditional structures (Bahrami 1992, Giuri et al. 2008, Zenger and Hesterly 1997).

Bertschek and Kaiser (2004) demonstrate that workplace reorganization in favor of group work and flat structures induces an increase in labor productivity that can be attributed to complementarities between IT investments and reorganizational efforts. This suggests that the fundamental capabilities of IT are enhanced within organizational contexts and managerial structures that promote decentralization, employee empowerment and job flexibility. In addition to structural shifts resulting from workplace reorganization plans or adaptation of new management methods, changes in corporate strategy are also responsible for new, emergent organizational structures. These structural arrangements are more effective if combined with IT assets that enhance the capability of the organization to exercise its intended strategy (e.g. Chari et al. 2008). The above considerations lead to Hypothesis 2 (H2):

H2: Information technology assets and changes in organizational structures of the firm due to workplace reorganization policies, alteration of management methods or introduction of new strategies function as complements in explaining firm performance.

2.4.3. Information technology and boundary changes of the firm

In contrast to intra-organizational aspects of OC and their interaction with IT, the inter-organizational dimension has received hardly any attention in the scientific literature. IT leads to distinctive boundary-spanning or breaking effects on the firm. The once very rigid and unbreachable boundaries of business are nowadays fading (Kanter 1991). This is encouraged by rapid development and proliferation of information technologies, as predicted by Malone et al. (1987). Zornoza and Alcami (1999) discuss the role of IT in enabling firms to break their boundaries and form network-based and virtual organizations. Similarly, Brynjolfsson et al. (1994) find supportive evidence that investment in IT is significantly associated with subsequent shrinkage of the firm boundaries. The extent and efficiency of strategic alliances (Faulkner 1994), networked organizations (Jarvenpaa and Ives 1994), subcontracting

R&D (Whittington 1991), virtual new product development (NPD) (Montoya et al. 2009), and outsourcing of non-core activities such as employee training, procurement functions or engineering tasks (Geroski and Gregg 1994, Leonardi and Bailey 2008, Sankaranarayanan and Sundararajan 2010) are also increased through appropriate external IT systems. These IT-based systems, such as electronic data interchange (EDI), enterprise application integration (EAI), supply chain management (SCM), interorganizational systems (IOS), and computer aided engineering (CAE) allow firms to share information across their boundaries, increase visibility of interfirm activities, reduce transaction and market coordination costs, and enable cross-boundary, collaborative projects.

IT not only leads to or accompanies new external forms of business organization but also complements the effectiveness of these forms in creating business value for the firm. For example, IT adoption complements the decision to engage in collaborative R&D or joint marketing with customers. This gives rise to alliances and loosely-coupled organizational forms (Sahaym et al. 2007). Similarly, Hitt (1999) find that increased use of IT is associated with decreases in vertical integration, ultimately leading to virtual forms of the enterprise. He highlights the catalytic role of OC by showing that firms that are less vertically integrated have higher demand for IT capital. The above considerations lead to Hypothesis 3 (H3).

H3: Information technology assets and changes in organizational boundaries of the firm due to formation of alliances or R&D partnerships, outsourcing or subcontracting of activities or introduction of newdistribution, marketing or servicing methods function as complements in explaining firm performance.

3. Empirical Models

A number of methods exist to empirically investigate organizational complementarities.[2] Rather simple methods are the *adoption or correlation approach* and the *interaction approach*. The adoption approach is the most basic method (e.g. Bresnahan et al. 2002, Caroli and Van Reenen 2001, Giuri et al. 2008). It relies on reduced-form estimations of the adoption of a complement conditional on the adoption of other complements, controlling for exogenous attributes of the adopter. Another version relies on conditional correlations between the residuals of reduced-form regressions of hypothesized complements on observable control variables. This method suffers from potential simultaneity of decisions to adopt different complementary resources. Another limitation is that this method solely looks at the interrelationships between complementary resources and not their joint effect on firm performance, which is of particular interest in the present study.

The interaction approach relates a measure of firm performance to a set of input factors, observed control variables, and interaction terms between hypothesized complements in either a single-equation production function setting or a system of structural equations (e.g. Bharadwaj et al. 2007, Black and Lynch 2001, Jeffers et al. 2008). This method looks at pair-wise (or higher-order)

[2] See Athey and Stern (1998) for a useful review and Carree et al. (2010) and Zand (2010) for further discussions.

interactions without considering the contextual conditions inside a system of interconnected variables that might potentially influence the relationships among these variables. Another shortcoming is that this method does not properly account for the mutual dependency between the strategic decisions to invest in IT resources and those to implement organizational changes.

In order to test the hypotheses, we employ two approaches, namely the *systems or clustering approach* and the *two-stage approach*. Following the general trend in the literature, we adopt a three-factor Cobb-Douglas production technology as the starting point for the model derivation:

$$Y_{i,t} = A_{i,t} L_{i,t}^{\alpha} K_{i,t}^{\beta} IT_{i,t}^{\delta} \tag{1}$$

Firm output $Y_{i,t}$ is a function of labor $L_{i,t}$, non-IT or conventional capital $K_{i,t}$, IT capital $IT_{i,t}$ and total factor productivity (TFP) $A_{i,t}$. TFP captures all the variables that affect firm output above the effects of the inputs. It reflects firm-specific heterogeneity such as production technology, process efficiency, and workforce knowledge. α, β and δ denote the elasticities of output with respect to the three input factors. Taking natural logarithms and re-writing the output in per-worker unit in (1) yields an equation where the dependent variable is labor productivity and the independent variables are logs of labor, non-IT and IT capital.

$$lp_{i,t} = a_{i,t} + \lambda l_{i,t} + \beta k_{i,t} + \delta it_{i,t} + \sum \varphi_m sd_m + \sum \theta_n td_n + \varepsilon_{i,t} \tag{2}$$

$lp_{i,t}$ denotes the natural logarithm of output per full-time equivalent (fte) employee while $l_{i,t}$, $k_{i,t}$ and $it_{i,t}$ denote the logarithms of the number of employees, conventional capital and IT capital of firm *I* at time *t* respectively. Sector and time dummies are represented by *sd* and *td* respectively. The two sigma's in (2) control for sector- and time-specific effects or shocks to labor productivity that influence all firms in a single industry or all firms in a specific year. Furthermore, $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. The scale elasticity of the production function is identical to $\alpha+\beta+\delta$ in the productivity equation (1) or alternatively $\lambda+\beta+\delta+1$ in (2).

3.1. Systems approach

Accounting for organizational change requires a further parameterization for $a_{i,t}$ in (2) that goes beyond the inclusion of industry and time dummy variables. In the systems approach, the joint contribution of IT and OC to TFP is captured through a set of 16 unique system or cluster dummy variables (i.e. S_{abcd}: *a*, *b*, *c*, $d \in \{0, 1\}$)

$$lp_{i,t} = \alpha l_{i,t} + \beta k_{i,t} + \delta it_{i,t} + \sum_{a=0}^{1}\sum_{b=0}^{1}\sum_{c=0}^{1}\sum_{d=0}^{1} \gamma_{abcd} S_{i,t,abcd} + \sum \varphi_m sd_m + \sum \theta_n td_n + \varepsilon_{i,t} \tag{3}$$

$S_{i,t,abcd}$ refers to the state of firm *i* at year *t,* depending on the adoption of 4 dichotomously-measured practices: *(a)* process OC, *(b)* structure OC, *(c)* boundary OC, and *(d)* high IT intensity. The systems approach works with reducing the continuous variables to dichotomous variables. Process, structure and boundary OC are dummies indicating the occurrence of the corresponding organizational changes. High IT intensity is a dummy variable taking the value 1 if the share of IT capital in total capital of the firm is greater than the average level of the firm's industry and 0 otherwise. The firm is at state $S_{abcd=0000}$ when it has neither introduced any sort of OC nor had a high IT intensity compared to its respective industry. It is at state $S_{abcd=1111}$ when it has undergone all the three sorts of OC and at the same time possessed a high IT intensity. Other combinations of practices are defined similarly.

The theory of supermodularity (Milgrom and Roberts 1990) implies that two practices P^a_i and P^a_j are complementary to each other with respect to an objective performance function *f*() if the following inequality holds for all possible values of other arguments of *f* (with the inequality holding "strictly" for at least one combination of other arguments):[3]

$$f(P_i^1, P_j^1, .) - f(P_i^1, P_j^0, .) \geq f(P_i^0, P_j^1, .) - f(P_i^0, P_j^0, .) \tag{4}$$

Superscript a in P^a_i stands for adoption (a = 1) or lack of a practice (a = 0).[4] The above inequality posits that the marginal return of practice *j* is greater (or at least identical) under the condition that activity *i* exists, irrespective of the adoption state of other practices that may influence *f*. In case of four practices as in model (3), inequality (4) is translated to a set of four simultaneous inequality conditions for any of the six pairs of practices:

$$\begin{aligned}
&C(a-b): && \gamma_{11cd} - \gamma_{10cd} \geq \gamma_{01cd} - \gamma_{00cd} && \forall cd: && cd \in \{00, 01, 10, 11\} \\
&C(a-c): && \gamma_{1b1d} - \gamma_{1b0d} \geq \gamma_{0b1d} - \gamma_{0b0d} && \forall bd: && bd \in \{00, 01, 10, 11\} \\
&C(a-d): && \gamma_{1bc1} - \gamma_{1bc0} \geq \gamma_{0bc1} - \gamma_{0bc0} && \forall bc: && bc \in \{00, 01, 10, 11\} \\
&C(b-c): && \gamma_{a11d} - \gamma_{a10d} \geq \gamma_{a01d} - \gamma_{a00d} && \forall ad: && ad \in \{00, 01, 10, 11\} \\
&C(b-d): && \gamma_{a1c1} - \gamma_{a1c0} \geq \gamma_{a0c1} - \gamma_{a0c0} && \forall ac: && ac \in \{00, 01, 10, 11\} \\
&C(c-d): && \gamma_{ab11} - \gamma_{ab10} \geq \gamma_{ab01} - \gamma_{ab00} && \forall ab: && ab \in \{00, 01, 10, 11\}
\end{aligned} \tag{5}$$

3.2 Two-stage approach

Inherent in (3) is that state variables (S) are assumed to be exogenously given. However, the character of OC variables in (3) may raise concerns about the endogeneity of OC in this model. Organizational changes can be a function or consequence of past technological investments of the firm. Dedrick et al. (2003: 1) conclude from their review of studies on IT investment and firm productivity that "IT is not simply a tool for automating existing processes, but more importantly is an enabler of organizational changes that can lead to additional productivity gains." Similarly, Zammuto et al. (2007) attribute the capacity of IT to induce or support organizational change to its affordances such as visualizing work processes and provoking virtual collaboration. Adoption of advanced IT-based manufacturing or service management technologies is also

[3] The practices are substitutable in function *f* if the same inequality holds with the ≥ sign replaced by the ≤ sign.
[4] Alternatively, this can be translated to high and low adoption intensities.

reported to enable organizational change (Colombo and Delmastro 2002, Leonardi 2007).

Alternatively, endogeneity of OC can be the result of simultaneity. Firms' managers may decide on their level and type of technological investments and organizational changes simultaneously. Bocquet et al. (2007) posit the idea that IT adoption is a consequence of a simultaneous process by which firms seek to adopt a bundle of complementary strategies, organizational practices and advanced technologies all together. Aral and Weill (2007) find evidence for a simultaneous interrelation such that firms with a high IT intensity tend to develop organizational capabilities more intensively and, at the same time, firms with strong organizational capabilities demand more IT.
To overcome these concerns, we extend the systems approach and develop a method to control for potential endogeneity of OC in our estimations.[5] It consists of two stages. In the first stage, the three types of organizational change are related to the labor, capital and sectoral data of the firm. The three equations that explain OC variables are then given by

$$OCP^*_{i,t} = a'_{i,t} + \lambda' l_{i,t} + \beta' k_{i,t} + \delta' it_{i,t} + \sum \varphi'_m sd_m + \sum \theta'_n td_n + \varepsilon'_{i,t} \quad (6)$$
$$OCS^*_{i,t} = a''_{i,t} + \lambda'' l_{i,t} + \beta'' k_{i,t} + \delta'' it_{i,t} + \sum \varphi''_m sd_m + \sum \theta''_n td_n + \varepsilon''_{i,t}$$
$$OCB^*_{i,t} = a'''_{i,t} + \lambda''' l_{i,t} + \beta''' k_{i,t} + \delta''' it_{i,t} + \sum \varphi'''_m sd_m + \sum \theta'''_n td_n + \varepsilon'''_{i,t}$$

OCP^*, OCS^* and OCB^* are continuous variables signifying the level of process, structure and boundary changes respectively. The level of change is latent and we only observe whether or not a firm has experienced a certain type of OC. Therefore, we define an indicator function *Ind*(.) that is equal to 1 if the condition that the firm has had a particular type of OC holds and 0 otherwise:

$$OCP_{i,t} = Ind(OCP^*_{i,t} > 0) \quad (7)$$
$$OCS_{i,t} = Ind(OCS^*_{i,t} > 0)$$
$$OCB_{i,t} = Ind(OCB^*_{i,t} > 0)$$

OCP, OCS and OCB are dichotomous variables corresponding to the events that the firm has had process, structure and boundary changes respectively. The system (7) is a trivariate probit model with $\varepsilon_{i,t} = (\varepsilon'_{i,t}, \varepsilon''_{i,t}, \varepsilon'''_{i,t})' \sim N(0, \sum)$.

The first stage controls for the endogeneity of OC variables under the assumption that the labor and capital inputs are exogenous to productivity.[6] The second stage includes estimation of an augmented production function. Model (3) is modified such that the state dummies are replaced by a set of propensities calculated from the first stage, and te model is extended with interactions of these propensities with the capital inputs. Propensities are calculated for each possible combination of OC variables and are included in the production function as proxies for organizational change. These propensities are likelihood

[5] Alternatively, we could employ an instrumental variable (IV) method. However, we could not find proper, strong instruments for OC.
[6] See section 4 for construction of the capital stock variables.

predictions (as the actual OC variables are latent and endogenous), each taking the a value between 0 and 1 Pr(x, y, z)∈ [0,1]) where x, y, z∈ {0, 1} are contingent on the observation of process, structure and boundary changes respectivily[7].

$$lp_{i,t} = a_{i,t} + \alpha l_{i,t} + \beta k_{i,t} + \delta it_{i,t} + \sum_{x=0}^{1}\sum_{y=0}^{1}\sum_{z=0}^{1} \gamma_{xyz} Pr_{i,t}(x,y,z) + \sum_{x=0}^{1}\sum_{y=0}^{1}\sum_{z=0}^{1} \mu_{xyz} Pr_{i,t}(x,y,z) * k_{i,t} + \sum_{x=0}^{1}\sum_{y=0}^{1}\sum_{z=0}^{1} \zeta_{xyz} Pr_{i,t}(x,y,z) * it_{i,t} + \sum \varphi_m sd_m + \sum \theta_n td_n + \varepsilon_{i,t} \quad (8)$$

In addition to estimating models (3) and (5) for the systems approach and models (6) and (8) for the two-stage approach, we also derived a version of these models where the three OC variables are combined into a single composite indicator. Construction of this indicator is discussed in section 4.2.3. More details on the specification of the empirical models with this indicator can be found in Zand (2010).

4. Data

4.1. Construction of the panel

Large-scale empirical studies are scarce in the field of IS (Sircar et al. 2000). Datasets containing observations suitable for firm-level analysis are even scarcer, as compared to those suitable for industry-level studies (Sircar and Choi 2009). For the purpose of this research, we developed a unique and extensive panel dataset for the Netherlands, characterized by three features. First, it is a large, representative sample of 32,619 firm-level observations from different enterprise size classes (i.e. small, medium, and large), over most economic sectors (141 sectors at 3-digit Eurostat NACE rev. 1.1) and a longitudinal time span of 13 years (1994-2006). Existing studies mainly use small datasets on large firms, usually from a limited number of industries and mainly from the US (Ennen and Richter 2010). This limits representativeness of their data samples and generalization of their results to different enterprise size classes, sectors and countries. Second, in contrast to earlier studies that use cross-section data, the size and time-series nature of the panel used in this study allows to deal with identification and endogeneity problems and attain consistent and precise estimations. Third, the time span analyzed is an interesting period covering substantial developments as well as stagnations in IT spending and IT-related OC that happened prior and subsequent to the dotcom bubble burst in 2000.

The panel is the result of linking 38 individual datasets covering annual financial data and productivity statistics of firms (PS Surveys: 1994-2006), annual data on investments by type of assets (INV Surveys: 1993-2005), bi-annual data on innovation input, throughput and output (CIS Surveys: 1996, 1998, 2000, 2002, 2004, 2006), and bi-annual data on R&D expenditures and personnel (RD Surveys: 1995, 1997, 1999, 2001, 2003, 2005). The panel has been supplemented with sectoral National Accounts (NA) data such as

[7] To avoid perfect collinearity in estimating model (8), Pr(0,0,0) is taken as the reference category.

investment deflators, output price indices, service lives of investment goods and depreciation rates.[8]

4.2. Construction of variables

4.2.1. Labor productivity

The dependent variable in the models, i.e. labor productivity in 1993 prices is measured as the log of value-added (at factor costs) per employee in full-time equivalent (fte). Value-added deflators at the sector-level are used to correct for inflation.

4.2.2. Capital inputs

IT and non-IT capital stock measures are constructed based on the Perpetual Inventory Method (PIM) using investment data and price indices for investment goods. The stock-flow relation for capital good of type *c* at the beginning of period *t* for firm *I* ($G_{c,i,t}$) reads:[9]

$$G_{c,i,t} = (1-d_{c,i})G_{c,i,t-1} + I_{c,i,t-1} \quad (9)$$

$I_{c,i,t-1}$ denotes the preceding year's investment in capital of type *c*. Equation (9) expresses that the previous year's capital stock decreases in economic value at a depreciation rate ($d_{c,i}$) that depends on the type of capital and sector of the firm. By using (9) we also assume a gestation lag of one year to account for the fact that capital investments take time after their installation before they become productive and part of the firm's bundle of effective inputs. In other words, $G_{c,i,t}$ is an indicator of a firm's capital input during period *t* measured at the beginning of the period (or, alternatively, end of the previous period). Therefore, we can consider investment capital to be exogenous for explaining productivity in year *t*.

To obtain the initial stock of capital goods (for *t* = 1) we rewrite (9) by backward substitution:

$$G_{c,i,1} = I_{c,i,0} + (1-d_{c,i})I_{c,i,-1} + (1-d_{c,i})^2 I_{c,i,-2} + (1-d_{c,i})^3 I_{c,i,-3} + ... = \sum_{s=0}^{\infty} I_{c,i,-s}(1-d_{c,i})^s = \quad (10)$$

$$I_{c,i,0}\sum_{s=0}^{\infty}\left[\frac{1-d_{c,i}}{1+gr_{c,i}}\right]^s = \frac{I_{c,i,1}}{d_{c,i}+gr_{c,i}}$$

In (10), $gr_{c,I}$ denotes the average growth rate of capital type *c* in the pre-sample period. This is the average rate at which expenditures in capital type *c* has grown (or declined) over years prior to the beginning of the period of analysis (1994-2006).

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[8] See Zand (2010) for a more detailed discussion of the data.

[9] In contrast to a number of similar studies, we do not apply any sort of imputation in calculating the capital stocks. Firm's *i* capital at time *t* is only constructed if a continuous time-series for all the past investments preceding *t* is available at our disposal.

For implementing (9) and (10), we extract capital investments from the annual Investment Surveys. IT investment includes expenditures in both computer hardware and software. Non-IT investment captures all other types of investment in fixed assets. Similar to output measures, nominal investment figures need to be transformed to real figures using appropriate investment deflators. This has been achieved by applying NA price indices for investment goods at the 3-digit NACE sector level. Deflators for IT investment are based on harmonized hedonic techniques to adjust for quality improvements of IT goods. Figure 2 depicts the development of output and investment deflators over the course of time. The index numbers shown in the figure are weighted averages over the whole Dutch economy. It is notable that prices of IT goods have declined over time while other types of investment goods and output have experienced price increases.

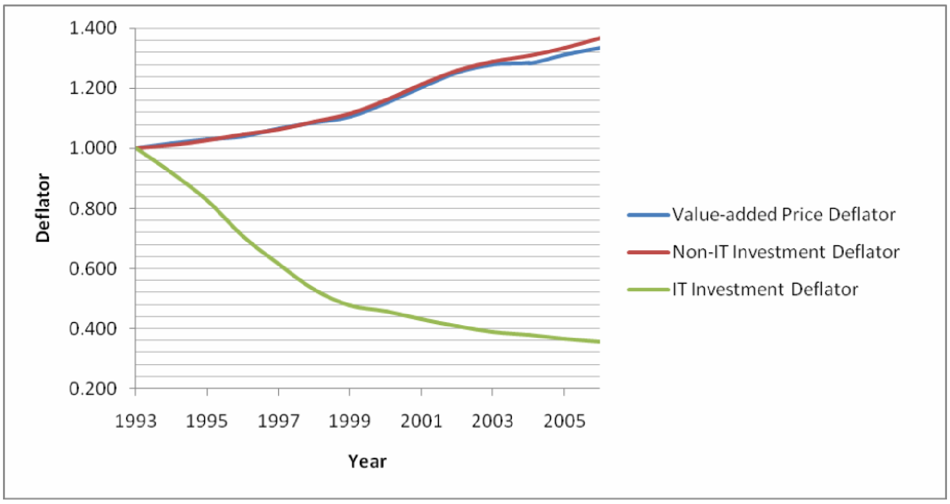

Figure 2: Development of Output and Input Deflators over the Period 1993-2006

Although constructing (real) investment time series at the firm level is feasible in principle, the application of (9) and (10) raises some complications. Equation (10) implicitly assumes a steady growth of investment over a long period, an assumption that is at odds with the very nature of investment patterns observable at the firm level. Investment behavior at the firm level can be very erratic. Moreover, investment cycles may change over time and differ between firms. As a consequence, the initial capital stocks calculated by (10) may be too dependent on the probability and size of investments in the first year. This can be circumvented by replacing $I_{c,i,1}$ with the average (real) investment of type c observed over the period of analysis.

Another complication concerns the calculation of depreciation rates. Here, it is important to distinguish between the price effects of use and obsolescence (Statistics Canada 2007). Computers, for instance, may undergo relatively little physical depreciation over their service life and yet they may experience markedly declines in resale value due to quick obsolescence. The availability of detailed annual NA data on the (expected) service life and the composition of different categories of capital assets at the sectoral level enabled us to estimate the average rates of depreciation for IT and non-IT capital over time. These depreciation rates are calculated as the inverse of the weighted sum of the service lives of different types of fixed assets:

$$d_{c,i} = \frac{1}{\sum_{k_c} SL_{k_c,i} * W_{k_c,i}} \tag{11}$$

$SL_{kc,i}$ is the firm *i*'s expected service life of capital asset type *c* and $W_{kc,i}$ is the share of this type of capital asset in total fixed assets of the firm's respective sector.[10] The average depreciation rates for the Dutch economy were estimated as 26.4% and 6.4% for IT and non-IT capital respectively. Among the sectors present in our sample, the Audio/Video & Telecom Equipment and Furniture & Wood Products exhibit the highest (31%) and lowest (20%) depreciation rates for IT respectively. Trade, Repair & Rental of Motor Vehicles and Base Metals Industry appear to be the sectors with the highest (13%) and lowest (3%) depreciation rates for non-IT capital respectively.[11]

Finally, we needed a dichotomous measure of the firm's IT intensity for constructing clusters in model (3). We calculate the share of IT capital in total capital and define a dummy variable accordingly. The dummy takes the value 1 if a firm's IT share in the total capital stock is above the average IT share in its corresponding industry and 0 otherwise.

4.2.3. Organizational changes

OC variables (OCP, OCS and OCB), the variables of main interest in the present study, are dummy variables, capturing the three primary dimensions of organizational change. Such a multi-dimensional measure allows for comparative study of different dimensions of change with respect to IT interactions and performance implications. OC variables are adopted from CIS (Community Innovation Survey).

OCP takes the value 1 if the firm has introduced significant changes or improvements in its internal business processes as a consequence of either (1) implementation of new or significantly improved production processes or technologies, operational routines or support activities or (2) implementation of knowledge management systems or policies. The post-2000 waves of CIS (i.e. 2000-2002, 2002-2004, and 2004-2006) include separate questions covering these two components while the pre-2000 waves (i.e. 1994-1996, 1996-1998, and 1998-2000) only include data on the first condition.

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[10] Dutch NA collects data on 15 asset types: 1) Dwellings, 2) Non-residential buildings, 3) Civil engineering construction works (e.g. roads and waterways), 4) Personal cars, 5) Other road transport vehicles, 6) Railroad transport vehicles, 7) Water transport vehicles, 8) Air transport vehicles, 9) Computers and other hardware, 10) Machinery and other equipment, 11) Cultivated assets (e.g. plants), 12) Other material/tangible assets, 13) Transfer costs of immovable properties (e.g. lands and buildings), 14) Software, and 15) Other immaterial/intangible assets.

[11] Further details on the construction of capital stock data can be found in Zand (2010).

OCS takes the value 1 if the firm has introduced significant changes or improvements in its internal organizational structures as a consequence of (1) new or fundamentally changed corporate strategies, (2) implementation of new, advanced management techniques, or (3) radical reorganizations. Pre-2000 waves of CIS include separate questions on these aspects while post-2000 waves combine them in a single question.

OCB takes the value 1 if the firm has introduced significant changes or improvements in its boundaries with external parties as a consequence of (1) introduction of new or significantly improved marketing concepts or strategies, distribution methods or sales channels (e.g. franchising/licensing or internet/direct sales), (2) adoption of cooperative arrangements or formal partnerships with third parties (e.g. customers, suppliers, competitors or universities), or (3) radical alteration of the firm's relations with other enterprises or public institutions (through e.g. alliances, outsourcing/offshoring or sub-contracting). The first two components are questioned in all waves of CIS while the third one is only available in post-2000 waves.[12]

CIS is a bi-annual survey. The above questions related to OC variables are being surveyed every two years about the status of the firm within the previous triennium. For example, the last wave of CIS used in the present study was conducted at early 2007 and asked about innovation activities and organizational changes during the 3-year period 2004-2006. If a firm indicates that it has undergone some sort of OC during this period, we assume that the value of associated OC variable is true for the three years of the period (i.e. 2004, 2005, and 2006). We consider this as a valid supposition as OC initiatives are not one-time, instantaneous but ongoing projects that might last for a long time before they complete. As to the issue of time-lags, suppose a firm has responded positively to a kind of OC in the 2004-2006 wave of CIS. When t = 2006, productivity of the firm is measured at the end of 2006, capital inputs refer to end of 2005 stocks (i.e. one year time-lag) and the corresponding OC indicator is true throughout the period 2004-2006, being at the end of 2006 or beginning of 2004 in extreme cases.[13]

To run a simple version of the models developed in subsections 3.1 and 3.2, we need an overall composite indicator (dummy) showing whether or not the firm has undergone major organizational changes at all (without respect to the type of change). In order to take communalities between and intensities of different types of organizational change into account, we employ confirmatory factor analysis (CFA). Principal Axis Factoring (PAF) and Kaiser Criterion are used to extract factors. A Cronbach's alpha of 0.720 indicates that we can attain a

[12] In this research, we follow the following scheme when applying the logical *OR* operator to individual sub-components or questions of a construct (for instance, when constructing OCP, OCS and OCB). The construct is 1 if the response to any of the corresponding sub-components is "Yes" and 0 if the answer to all of them is "No". It is set to missing if the answer to at least one of the sub-components is missing and the answer to none of them is "Yes".

[13] Assuming a linear completion rate for OC projects, the time-lag between measuring OC initiatives and firm productivity would be then 1.5 years on average.

reliable and consistent score. One single factor with eigenvalue greater than one, accounting for 66.9% of variance, was extracted (n= 32,619). A KMO measure of 0.735 indicates a satisfactory sampling adequacy. Finally, Bartlett's method is used to estimate factor scores. The extracted factor from CFA is a continuous, aggregate measure of organizational change. In order to transform it to a dummy variable, we compare its value for each firm with the average of the firm's respective sector. This approach is appropriate as organizational change patterns and requirements are very dependent on the industry in which a firm operates.

4.3. Descriptive statistics

Table 1 reports the descriptives of the relevant variables. The sample contains 32,619 firm observations. The average firm in the sample has 166 employees and generates an annual €51.4 and €10.9 million in turnover and value-added. The average firm has €19.9 million in total capital, from which €19.3 million can be considered as non-IT capital; this makes the share of IT capital in the sample about 11% on average. The IT capital of the average firm has experienced an annual growth of 14% during the time span 1994-2006 while, in the same period, non-IT capital has only grown by 1% annually. Sixty-seven percent of the sampled firms belong to a larger enterprise group and 21% are part of a multinational enterprise.

Organizational change can be considered as a common phenomenon as 64% of the sampled firms introduced some sort of organizational change during 1994-2006. Structure changes are the most common type of OC with observations in 43% of the sample, followed by process and boundary changes with 42% and 36% respectively. Osterman (1994) and Wittington et al. (1999) report comparable, yet slightly higher proportions, for their surveys of American and European enterprises respectively. These surveys primarily include large enterprises (which are more intensive adopters of OC) while our sample includes all firm size classes.

Table 1: Descriptive statistics

Variable	Mean	Std. Dev.	Observation
Employees (fte)	166.3	525.0	32619
• *Manufacturing*	*159.7*	*365.9*	*15613*
• *Services*	*177.6*	*700.8*	*13698*
Total turnover (1000 €)	51426.6	239284.4	32619
• *Manufacturing*	*52785.7*	*266693.5*	*15613*
• *Services*	*56445.3*	*233746.7*	*13698*
Value-added (1000 €)	10875.3	52977.2	32619
• *Manufacturing*	*13605.5*	*71161.3*	*15613*
• *Services*	*9042.9*	*29350.9*	*13698*
Labor productivity (€/fte)	60136.2	114020.4	32619
• *Manufacturing*	*60799.0*	*62552.9*	*15613*
• *Services*	*65112.2*	*161902.8*	*13698*
Total capital (1000 €)	19942.0	100247.4	32619
• *Manufacturing*	*32358.1*	*136779.2*	*15613*
• *Services*	*9369.9*	*45094.1*	*13698*
Non-IT capital (1000 €)	19286.6	99298.0	32619
• *Manufacturing*	*31811.7*	*135765.7*	*15613*
• *Services*	*8517.7*	*43550.7*	*13698*
IT capital (1000 €)	655.5	3558.4	32619
• *Manufacturing*	*546.2*	*3780.2*	*15613*
• *Services*	*852.2*	*3678.9*	*13698*

Table 1 continued

Non-IT capital share (%)	88.7	15.7	32619
• *Manufacturing*	*94.4*	*8.5*	*15613*
• *Services*	*82.4*	*19.6*	*13698*
IT capital share (%)	11.3	15.7	32619
• *Manufacturing*	*5.6*	*8.5*	*15613*
• *Services*	*17.6*	*19.6*	*13698*
Non-IT capital intensity (€/fte)	94819.5	238704.1	32619
• *Manufacturing*	*141380.5*	*259543.7*	*15613*
• *Services*	*58419.7*	*229065.6*	*13698*
IT capital intensity (€/fte)	3858.0	14051.1	32619
• *Manufacturing*	*2817.3*	*5033.8*	*15613*
• *Services*	*5476.0*	*20650.3*	*13698*
Non-IT capital growth (%)	1.1	2.3	32619
• *Manufacturing*	*0.9*	*2.8*	*15613*
• *Services*	*0.8*	*1.8*	*13698*
IT capital growth (%)	13.9	3.7	32619
• *Manufacturing*	*11.8*	*3.9*	*15613*
• *Services*	*15.5*	*2.1*	*13698*
Group (%)	67.1	47.0	32619
• *Manufacturing*	*67.8*	*46.7*	*15613*
• *Services*	*67.8*	*46.7*	*13698*
Multinational (%)	20.8	40.6	32210
• *Manufacturing*	*25.1*	*43.3*	*15398*
• *Services*	*20.3*	*40.3*	*13698*
Organizational change (%)	64.2	48.0	32619
• *Manufacturing*	*71.3*	*45.3*	*15613*
• *Services*	*59.6*	*49.1*	*13698*
Structure changes (%)	43.3	49.5	32619
• *Manufacturing*	*46.2*	*49.9*	*15613*
• *Services*	*41.6*	*49.3*	*13698*
Process changes (%)	42.1	49.4	32619
• *Manufacturing*	*51.2*	*50.0*	*15613*
• *Services*	*36.5*	*48.2*	*13698*
Boundary changes (%)	35.5	47.9	32619
• *Manufacturing*	*41.4*	*49.3*	*15613*
• *Services*	*31.9*	*46.6*	*13698*

Manufacturing and services firms are of comparable size, with firms in the latter group being slightly larger. The size distribution, though, is much diverse for the services sector. Not surprisingly, manufacturing firms are more capital-intensive. Services firms, however, are more IT-intensive. In terms of both per worker and per euro of total fixed assets, services firms possess more IT capital. Per worker, services firms have almost twice as much IT as their manufacturing counterparts; per unit of capital, services firms are three times more IT-intensive. Another notable difference is the spread of IT intensity among companies, which is much larger among services firms. Hence, there are more remarkable differences among services than manufacturing firms with respect to their IT-orientation. While the growth rate of non-IT capital is comparable between the two industries, services firms have experienced a greater growth in their stock of IT capital over the period 1994-2006. Furthermore, manufacturers seem to be more aggressive adopters of organizational transformations than service providers; organizational changes of any type, especially process and boundary changes, are more common among manufacturing companies. Yet, the spread of OC is more or less the same between the two sectors.

The coverage of both manufacturing and services industries enables us to conduct a comparative study to unveil the major differences in creating value from IT investments between these two branches of the economy. Table 2 demonstrates the sectoral distribution of the sample.[14] Our sample consists of 48% manufacturing, 42% services and 10% construction firms. It represents almost all major manufacturing industries, although the IT-using sectors are better represented than the IT-producing sectors. The services sector of the sample is less representative. A number of very intensive users of IT and adopters of OC such as the financial sector, telecom services and media/entertainment industry are mostly missing. We expect that if the sample represented these missing industries, the difference in the level of IT-intensity between the services and manufacturing firms would be even larger while the difference in the frequency of organizational change between the two sectors would be smaller.

Table 2: Sectoral distribution of the sample

Sector	# of firms	% of sample
Manufacturing	**15613**	**47.87**
Pharmaceuticals, Chemicals and Related Products	1254	3.84
Machinery and Electrical Apparatus Manufacturing	2755	8.44
Electronics, Computers and Office Equipment	503	1.54
Medical/Optical, Audio/Video and Telecom Devices	652	2.00
Auto Industry and Transportation Equipment	653	2.00
Food, Beverage and Tobacco	2122	6.51
Textile, Clothing and Leather Industry	94	0.29
Paper and Related Materials	959	2.94
Printing and Publishing	155	0.48
Petroleum Industry	124	0.38
Rubber, Plastics and Synthetic Materials	1089	3.34
Glass, Pottery and Related Products	672	2.06
Base Metals Industry	458	1.41
Fabricated Metal Products	2780	8.52
Furniture and Wood Products, Recycling and Other Industries	1343	4.12
Construction (and related activities)	**3308**	**10.14**
Services	**13698**	**41.99**
Computer Services	351	1.08
Professional and Business Services	2383	7.31
Trade, Repair and Rental of Vehicles and Related Services	1172	3.59
Wholesale and Commission Trade	6868	21.05
Retail Trade and Catering Services	2849	8.73
Environmental, Cultural and Catering Services	75	0.23
Total	**32619**	**100**

[14] We use sector indicators at 3-digit in our analyses. However, for presentation, we report them at 2-digit. A more detailed sectoral break-down of the sample is available in Zand (2010).

5. Empirical Results

5.1.Baseline regression

Regression (1) in Table 3 reports the results of estimating model (2) for the whole sample (A), as well as for manufacturing (M) and services (S). The model is estimated using both the maximum likelihood estimator (MLE) and the generalized least squares (GLS) estimator with (robust) standard errors corrected for heteroskedasticity of error terms and within-cluster correlations.[15]

Table 3: Regression results for model (1) - (3)

Variable	Sample	Regression (1) (baseline)	% sample	Regression (2) (system)	Regression (3) (system)
ln(Employee)	A	**-.309(.01)**	---	**-.310(.01)**	**-.311(.01)**
	M	***-.174(.01)***	---	***-.175(.01)***	***-.176(.01)***
	S	***-.411(.01)***	---	***-.412(.01)***	***-.413(.01)***
ln(NIT)	A	**.119(.00)**	---	**.117(.01)**	**.117(.01)**
	M	***.098(.01)***	---	***.093(.01)***	***.093(.01)***
	S	***.129(.01)***	---	***.128(.01)***	***.128(.01)***
n(IT)	A	**.041(.01)**	---	**.043(.01)**	**.043(.01)**
	M	***.030(.01)***	---	***.033(.01)***	***.033(.01)***
	S	***.054(.01)***	---	***.055(.01)***	***.055(.01)***
Constant	A	**9.994(.50)**	---	---	---
	M	***9.882(.08)***	---	---	---
	S	***10.263(.21)***	---	---	---
Cluster (00)	A	---	38.4	Reference	---
	M	---	*35.2*	Category	---
	S	---	*39.6*		---
Cluster (01)	A	---	21.9	**-.030(.01)**	---
	M	---	*18.1*	***-.026(.01)***	---
	S	---	*24.5*	***-.032(.01)***	---
Cluster (10)	A	---	25.4	.008(.01)	---
	M	---	*31.4*	*.012(.01)*	---
	S	---	*21.4*	*.011(.01)*	---
Cluster (11)	A	---	14.4	**.023(.01)**	---
	M	---	*15.3*	*.002(.01)*	---
	S	---	*14.5*	***.041(.01)***	---
Cluster (0000)	A	---	22.8	---	Reference
	M	---	*18.9*	---	Category
	S	---	*25.2*	---	
Cluster (0001)	A	---	13.0	---	**-.032(.01)**
	M	---	*9.8*	---	***-.024(.01)***
	S	---	*15.2*	---	***-.042(.01)***
Cluster (0001)	A	---	13.0	---	**-.032(.01)**
	M	---	*9.8*	---	***-.024(.01)***
	S	---	*15.2*	---	***-.042(.01)***
Cluster (0010)	A	---	2.5	---	**.052(.01)**
	M	---	*2.7*	---	***.054(.02)***
	S	---	*2.4*	---	*.030(.02)*

[15] To correct for heteroskedasticity of error terms, the Huber-White Sandwich method is employed (White 1980). To correct for intra-cluster dependencies (i.e. observations of a single firm over time), the method of Froot (1989) is used.

Table 3 continued

Cluster (0011)	A	---	1.8	---	.004(.02)
	M	---	*1.7*	---	*-.022(.02)*
	S	---	*1.8*	---	*.013(.03)*
Cluster (0100)	A	---	6.3	---	-.002(.01)
	M	---	*5.2*	---	*-.005(.02)*
	S	---	*6.5*	---	***-.035(.02)***
Cluster (0101)	A	---	3.3	---	-.015(.01)
	M	---	*2.7*	---	*-.011(.02)*
	S	---	*3.8*	---	*-.033(.02)*
Cluster (0110)	A	---	5.2	---	.013(.01)
	M	---	*4.9*	---	*.000(.02)*
	S	---	*5.4*	---	*.012(.02)*
Cluster (0111)	A	---	2.9	---	.017(.01)
	M	---	*2.8*	---	***-.041(.02)***
	S	---	*3.2*	---	***.053(.02)***
Cluster (1000)	A	---	6.7	---	.011(.01)
	M	---	*8.4*	---	*.007(.01)*
	S	---	*5.5*	---	*.018(.02)*
Cluster (1001)	A	---	3.8	---	-.016(.01)
	M	---	*3.9*	---	*-.016(.02)*
	S	---	*3.8*	---	*-.019(.02)*
Cluster (1010)	A	---	3.7	---	**.053(.01)**
	M	---	*5.4*	---	***.041(.02)***
	S	---	*2.4*	---	***.042(.02)***
Cluster (1011)	A	---	2.4	---	**.058(.02)**
	M	---	*2.9*	---	***.044(.02)***
	S	---	*2.1*	---	***.049(.03)***
Cluster (1100)	A	---	5.6	---	.004(.01)
	M	---	*6.6*	---	*.013(.01)*
	S	---	*5.1*	---	*.002(.02)*
Cluster (1101)	A	---	2.9	---	**.033(.01)**
	M	---	*3.1*	---	*.021(.02)*
	S	---	*3.0*	---	*.032(.022)*
Cluster (1110)	A	---	10.9	---	.008(.01)
	M	---	*14.5*	---	*.019(.01)*
	S	---	*8.5*	---	*.001(.02)*
Cluster (1111)	A	---	6.1	---	**.027(.01)**
	M	---	*6.5*	---	*.011(.02)*
	S	---	*6.1*	---	***.035(.02)***
			Model Diagnostics		
Observations	A	32619	32619	32619	32619
	M	*15613*	*15613*	*15613*	*15613*
	S	*13698*	*13698*	*13698*	*13698*
Log Likelihood	A	-14074		-14047	-14028
	M	*-5830*		*-5824*	*-5811*
	S	*-6400*		*-6379*	*-6370*
Pseudo-R^2	A	0.303		0.303	0.305
	M	*0.295*		*0.295*	*0.297*
	S	*0.288*		*0.288*	*0.289*
Model LR Test		0.000		0.000	0.000

Samples: A (All), M (Manufacturing), S(Services). Cluster (abcd) denotes S_{abcd} in model (3) where *a*, *b*, *c*, and *d* indicate process OC, structure OC, boundary OC, and high IT intensity respectively. Similarly, cluster (xy) is constructed based on the overall OC indicator where *x* and *y* indicate organizational change and high IT intensity respectively. Estimations are based on MLE for unbalanced panels. Significant estimates (at least at 10%) appear in bold, with robust standard errors are shown in parentheses. The Likelihood Ratio test is conducted for all model parameters.

We obtain a pseudo-R^2 of around 0.3, which is satisfactory given the overwhelming firm heterogeneity in the sample. The constant term denotes the remaining (unexplained) part of TFP and has a point estimate of about 10.0 Euro per fte. Regression (1) shows an output elasticity of 0.12 and 0.04 for non-IT and IT capital respectively. These elasticities are comparable with those reported in earlier studies in similar settings (e.g. Brynjolfsson and Hitt 1996, 2003, Hempell 2005, Sircar and Choi 2009). The results indicate that doubling the stock of IT and non-IT capital leads to 4% and 12% growth in labor productivity respectively, ceteris paribus. The capital elasticities are significantly larger for services, judged at 1% significance level using the standard Chow test.

The higher output elasticity of IT in services compared to manufacturing highlights the increasingly important role of information technology in services as evidenced by, among others, Brynjolfsson and Hitt (1995), Quinn et al. (1987) and Roach (1991). An explanation is that services firms are in general more knowledge-intensive than manufacturing firms are. The higher intensity and importance of knowledge in services makes computers a more important tool for processing information and codifying/assimilating knowledge. Another explanation relates to the labor mix in services and manufacturing, where the former has, on average, a higher proportion of educated and technologically proficient workers, who are more likely to possess the required capability and specialized knowledge to properly use advanced IT systems to improve organizational productivity (Francalanci and Galal 1998, Melville et al. 2007).

The third explanation concerns the nature of core value-adding activities and the role of innovation therein. The services sector mainly produces intangible outputs and can thus benefit more from the digital options enabled by IT (Sambamurthy et al. 2003, Zammuto et al. 2007). In this segment of the economy, business processes deal more with immaterial goods such as information and knowledge and less with physical goods. This provides more opportunities for IT to streamline and renovate business processes of the firm. Manufacturing firms, though, rely more on traditional R&D-based innovation and face more limits in digitizing their bottom line activities.

Combining the estimates of regression (1) and the means of output and input variables, allows us to calculate the marginal product (MP) of IT and non-IT capital. For the whole sample, the marginal product is 4.0 and 0.5 for IT and non-IT capital respectively. This indicates promising potentials for IT investments with a gross rate of return that is as much as eight times that of conventional types of capital.These figures are 3.1 and 0.2 for manufacturing and 5.1 and 0.9 for services respectively. The scale elasticity amounts to 0.85, 0.95, and 0.77 for the whole, manufacturing and services sample respectively, i.e. we face decreasing returns-to-scale (more dominantly in services).

5.2. Systems approach

Regressions (2) and (3) in Table 3 report the results of estimating model (3) after using the maximum likelihood estimator.[16] In regression (2), we use the overall OC indicator while in regression (3) we distinguish between the three types of OC. In comparison with the baseline specification, the results of the systems approach are robust for the scale and output elasticities as well as for other key model parameters. The fourth column shows the relative distribution of different cluster types in the sample. Consider firms with at least an above average OC or IT intensity (excluding cluster (00)). It is more common for services firms to have overinvestments in IT that are not accompanied by high levels of OC (24.5%) while it is more common for manufacturing firms to have high OC intensity coupled with underinvestments in IT (31.4%).

Output elasticities of capital and labor in regressions (2) and (3) of Table 3 are comparable to those in the baseline regression. Regression (2) includes estimates of three clusters relative to the base cluster (00).[17] The results endorse the idea of complementarity between IT and OC. Firms that heavily invest in IT, but fail to accommodate required organizational changes (cluster (01)), face productivity decline in comparison to the reference group. This finding reflects the argument of Milgrom and Roberts (1995) that partial or piecemeal implementation of organizational change leads to negative impacts of firm performance. Similarly, firms that fail to couple their OC investments with proper levels of IT capital experience positive but insignificant effects on their productivity. This relates to the situation when a company invests heavily in certain organizational changes but not sufficiently in enabling technologies that can support those changes and resulting new structures and/or processes. Under these conditions, OC efforts are not significantly productive as they impose substantial costs and make (some of) the old routines, structures or professions of the firm ineffective/obsolete. The only group of firms that manage to acquire significant productivity improvement from their investments are those that jointly invest in IT and OC, i.e. cluster (11) (remarkably, the impact is positive but insignificant and very small for the manufacturing sector).

Regression (3) shows that firms with a high IT intensity experience a positive impact on their productivity only if they combine technology investments with a proper mix of organizational changes. If IT is not accompanied by any type of OC (cluster (0001)), we observe a significantly negative effect on productivity. IT combined with all or certain pairs of OC types demonstrates a significantly positive contribution to productivity (clusters (1111), (1011), and (1101)). The effects are always significantly stronger in services than in manufacturing. In a specific case, i.e. combination of high IT intensity and structure and boundary changes together, the productivity effect is significantly negative in the manufacturing sector, while positive in the services sector (cluster (0111)).

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[16] The constant term of equation (3) is suppressed in order to generate estimates for all the clusters.

[17] The base cluster refers to all firms with low levels of OC and IT intensity (i.e. below their industry average).

Another finding is the significantly positive impact of joint process and boundary changes at low levels of IT (cluster (1010)) and that of boundary changes alone in the manufacturing sector (cluster (0010)). This corroborates the importance of boundary-spanning, inter-firm developments to productivity of the firm, even when these developments are not necessarily IT-based.

The next step is to use the estimated state coefficients (i.e. S_{abcd}) and compare them against the set of inequality restrictions in (5), in order to test for the existence of complementary or substitutable practices. The proper method for the joint test of regression coefficients under multiple inequality constraints (and the corresponding Wald criteria) is introduced in Gourieroux et al. (1982), Kodde and Palm (1986), and Wolak (1989).[18]

Table 4: Formal Tests of Complementarity based on the Supermodularity Theory

	Practices (H) Sample (V)	OCB-IT	OC-IT	OCP-IT	OCS-IT
H0: Complementarity	**A**	0.000	0.000	0.000	0.901
	10%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***
	5%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***
	1%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***
	M	1.517	0.000	0.222	5.020
	10%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	*(Indecisive)*
	5%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	*(Indecisive)*
	1%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***
	S	0.000	0.061	0.000	0.000
	10%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***
	5%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***
	1%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***

Samples: A (All), M (Manufacturing), S (Services). Wald test of inequality restrictions based on MLE estimates. Lower bound (LB) and upper bound (UB) critical values based on the Kodde-Palm method at different significance levels are: 10%: LB=1.6, UB=7.1; 5%:LB=2.7, UB=8.8; 1%: LB=5.4; UB= 12.5.

Table 4 reports the test results against the null hypothesis that a complementary relationship exists between any pair of practices under study. The findings clearly imply complementarity between IT and different dimensions of OC. The test results for complementarity between IT and OCB are not decisive at 5% and 10% significance levels in the manufacturing sector.

5.3. Two-stage approach

In response to endogeneity concerns, we developed the two-stage method. In the first stage (model (6)), OC variables are estimated using a multivariate probit system of equations that accounts for inter-equation correlations. The system can be estimated by simulated maximum likelihood using the Geweke-Hajivassiliou-Keane (GHK) simulator (Train 2003). Table 5 presents the results

[18] See Mohnen and Roller (2005) for an application of this method. To construct the test statistics, we wrote a computer program in MATLAB. The program can be made available upon request.

of the first stage.[19,20] Table 5 shows that firms with larger stocks of IT endowments are more likely to undertake organizational changes. This effect is present for all categories of OC. The significant enabling effect of non-IT capital is generally weaker and even missing in some cases (especially in services industries). An interesting finding is the significantly negative impact of conventional capital on the probability of structural changes (in the services sector). Firms with large stocks of (quasi-)fixed assets face greater degrees of routinization, structural inflexibility/immobility, and internal resistance to re-organization, which discourage or hamper their structural change initiatives.[21] These firms apparently do not face such severe inertia for changing their business processes or external boundaries. The findings also indicate that bigger companies are more inclined to undergo organizational changes, as revealed by the positive coefficient of *ln(Employee)*.

Table 5: Regression Results for Model (6), Maximum Likelihood based on GHK Simulator

1st-stage Model	Sample	OC (4)	OCP (5)	OCS (6)	OCB (7)
ln(Employee)	A	**.476(.02)**	**.294(.01)**	**.237(.01)**	**.278(.01)**
	M	***.667(.04)***	***.335(.01)***	***.301(.01)***	***.353(.01)***
	S	***.326(.03)***	***.245(.01)***	***.174(.01)***	***.189(.01)***
ln(NIT)	A	**.098(.02)**	**.055(.01)**	.007(.01)	**.021(.01)**
	M	***.127(.03)***	***.105(.01)***	*.007(.01)*	***.044(.01)***
	S	***.069(.03)***	*.008(.01)*	***-.019(.01)***	*.000(.01)*
ln(IT)	A	**.109(.01)**	**.083(.01)**	**.106(.01)**	**.107(.01)**
	M	***.137(.02)***	***.062(.01)***	***.118(.01)***	***.140(.01)***
	S	***.085(.029)***	***.088(.01)***	***.099(.01)***	***.086(.01)***
Sector dummies		Yes	Yes	Yes	Yes
Time dummies		Yes	Yes	Yes	Yes
Observations	A	32619		32619	
	M	*15613*		*15613*	
	S	*13698*		*13698*	

[19] Polder et al. (2010) use a similar approach in estimating their pseudo-CDM system of innovation equations. For a relevant mathematical treatment, see Appendix A in Polder et al. (2010).

[20] Due to space constraints, we only report the regression coefficients. Calculating the marginal effects, their standard errors and the propensities in a triprobit system of equations follows a specific bootstrapping algorithm. The marginal effects lead us to the same conclusions as the regression coefficients. The results are available upon request.

[21] In contrast to conventional capital, IT is a General Purpose Technology (GPT) that is generally designed to function ina broad range of applications and exhibits great deals of redeployability in new environments and adaptability to new uses.

Table 5 continued

Model diagnostics

Log Likelihood	A	-16081	-55521
	M	*-7783*	*-27611*
	S	*-6705*	*-22704*
Rho (ρ)	A	ρ=0.678	ρ12=.356, ρ13=.443, ρ23=.643
	M	*ρ=0.697*	*ρ12=.331, ρ13=.409, ρ23=.543*
	S	*ρ=0.683*	*ρ12=.389, ρ13=.486, ρ23=.700*
Model LR Test		0.000	0.000

Samples: A (All), M (Manufacturing), S(Services). Estimations are based on a triprobit system of simultaneous equations for OCP, OCS and OCB. In case of a single OC indicator, panel tobit is used. Significant estimates (at least at 10%) appear in bold, with robust standard errors shown in parentheses. The Likelihood Ratio test is conducted for all model parameters.

Table 6 reports the results of the second stage, which consists of estimating model (8) using the predicted propensities (to change) from the first stage. We use predictions from a univariate or trivariate probit model, depending on using the overall OC indicator (regression (8) and (9)) or distinguishing between different types of OC (regression (10) and (11)). In regression (8) and (9), the elasticity of non-IT and especially IT are higher than those reported in the baseline regression (1). An interesting observation, when endogeneity of OC is taken into account, is the negative contribution of OC to labor productivity. A related observation is the significantly negative interaction between non-IT capital and OC (except for services) and the significantly positive interaction between IT capital and OC in regression (9).

Table 6: Regression Results for Model (8), Maximum Likelihood Estimator

2nd-stage Model MLE	**Sample**	**Regression (8)**	**Regression (9)**	**Regression (10)**	**Regression (11)**
		Dependent Variable = log (Labor Productivity)			
ln(Employee)	A	**-.278(.01)**	**-.284(.01)**	**-.383(.01)**	**-.337(.01)**
	M	***-.093(.01)***	***-.104(.01)***	***-.240(.02)***	***-.275(.03)***
	S	***-.399(.01)***	***-.392(.01)***	***-.447(.01)***	***-.434(.02)***
ln(NIT)	A	**.130(.01)**	**.127(.01)**	**.114(.01)**	.005(.01)
	M	***.124(.01)***	***.123(.01)***	***.116(.02)***	*.108(.03)*
	S	***.134(.01)***	***.142(.01)***	***.125(.01)***	*.021(.02)*
ln(IT)	A	**.053(.00)**	**.071(.01)**	**-.013(.01)**	**.020(.01)**
	M	***.057(.00)***	***.062(.01)***	***-.022(.01)***	*-.041(.03)*
	S	***.060(.00)***	***.074(.01)***	***.020(.01)***	*.012(.01)*
		1st-stage Model = Probit			
Pr(1)	A	**-.115(.01)**	**-.391(.04)**		
	M	***-.202(.01)***	***-.099(.05)***		
	S	***-.068(.02)***	***-.635(.07)***		
Pr(1)*ln(NIT)	A	---	**-.004(.01)**		
	M	---	***-.023(.01)***		
	S	---	***.026(.01)***		
P(1)*ln(IT)	A	---	**.029(.01)**		
	M	---	***.023(.00)***		
	S	---	***.016(.01)***		

Table 6 continued

		1st-stage Model = Triprobit	
Pr(0,0,1)	A	**-.887(.34)**	**9.881(2.23)**
	M	***-1.017(.54)***	*1.268(3.38)*
	S	***1.001(.55)***	*4.908(3.54)*
Pr(0,1,0)	A	**1.244(.23)**	**2.118(.95)**
	M	***1.818(.31)***	***5.403(1.46)***
	S	*.292(.53)*	*.517(1.95)*
Pr(0,1,1)	A	**1.883(.31)**	**-2.029(1.16)**
	M	*.853(.60)*	*.836(1.64)*
	S	***.788(.42)***	*-3.836(2.37)*
Pr(1,0,0)	A	-.016(.33)	**-16.677(1.64)**
	M	*-.715(.61)*	***-9.914(2.32)***
	S	***-1.218(.56)***	***-12.134(3.04)***
Pr(1,0,1)	A	**2.443(.20)**	-.044(1.17)
	M	***.904(.47)***	*-6.784(1.80)*
	S	***3.146(.42)***	***4.917(2.95)***
Pr(1,1,0)	A	**-1.922(.27)**	**-4.418(1.04)**
	M	*-.802(.52)*	***6.422(1.56)***
	S	***-1.924(.34)***	***-2.973(1.52)***
Pr(1,1,1)	A	**1.735(.16)**	**-1.471(.51)**
	M	***1.037(.37)***	*.341(.88)*
	S	***1.691(.25)***	*-.470(.89)*
Pr(0,0,1)*ln(NIT)	A	---	**-1.017(.12)**
	M	---	*-.151(.17)*
	S	---	***-.356(.19)***
Pr(0,1,0)*ln(NIT)	A	---	-.076(.05)
	M	---	*-.591(.09)*
	S	---	***-.206(.11)***
Pr(0,1,1)*ln(NIT)	A	---	**.465(.08)**
	M	---	*.-151(.11)*
	S	---	***.640(.15)***
Pr(1,0,0)*ln(NIT)	A	---	**1.383(.09)**
	M	---	***.623(.13)***
	S	---	***.818(.16)***
Pr(1,0,1)*ln(NIT)	A	---	.114(.08)
	M	---	*.464(.10)*
	S	---	*.025(.20)*
Pr(1,1,0)*ln(NIT)	A	---	**-.237(.06)**
	M	---	***-.240(.09)***
	S	---	*.072(.10)*
Pr(1,1,1)*ln(NIT)	A	---	**.148(.03)**
	M	---	*.045(.04)*
	S	---	*-.030(.04)*
Pr(0,0,1)*ln(IT)	A	---	**.531(.12)**
	M	---	*.313(.19)*
	S	---	*.090(.20)*
Pr(0,1,0)*ln(IT)	A	---	-.033(.06)
	M	---	*.168(.11)*
	S	---	*.159(.12)*
Pr(0,1,1)*ln(IT)	A	---	**-.197(.09)**
	M	---	*.194(.15)*
	S	---	***-.292(.17)***

Table 6 continued

Pr(1,0,0)*ln(IT)	A			---	**-.423(.08)**
	M			---	*-.054(.12)*
	S			---	*.012(.18)*
Pr(1,0,1)*ln(IT)	A			---	-.063(.09)
	M			---	*-.146(.13)*
	S			---	*-.235(.23)*
Pr(1,1,0)*ln(IT)	A			---	**.465(.07)**
	M			---	*-.119(.11)*
	S			---	*-.039(.13)*
Pr(1,1,1)*ln(IT)	A			---	-.002(.02)
	M			---	*.000(.04)*
	S			---	***.181(.05)***
Sector dummies		Yes	Yes	Yes	Yes
Time dummies		Yes	Yes	Yes	Yes
			Model Diagnostics		
Observations	A	32619	32619	32619	32619
	M	*15613*	*15613*	*15613*	*15613*
	S	*13698*	*13698*	*13698*	*13698*
Log Likelihood	A	-14074	-13985	-13811	-13488
	M	*-5830*	*-5798*	*-5773*	*-5531*
	S	*-6400*	*-6360*	*-6356*	*-6294*
Pseudo-R^2	A	0.303	0.307	0.318	0.339
	M	*0.295*	*0.290*	*0.309*	*0.343*
	S	*0.288*	*0.293*	*0.291*	*0.301*
Model LR Test		0.000	0.000	0.000	0.000

Samples: A (All), M (Manufacturing), S(Services).Pr(x,y,z) denotes the predicted propensity (likelihood)associated with the (x,y,z) configuration as in model (8) where x, y, and z indicate process, structure, and boundary changes respectively. Pr(w) is defined similarly based on the overall OC indicator.Pr(0,0,0) and Pr(0) are the reference categories. Estimations are based on MLE for unbalanced panels. Significant estimates (at least at 10%) appear in bold, with robust standard errors shown in parentheses. The Likelihood Ratio test is conducted for all model parameters.

A first finding from regression (10) is that the IT elasticity turns into a negative value for manufacturing firms if the endogeneity of OC (and thereby the enabling effect of IT) is accounted for. In the services sector, the IT elasticity keeps its positive sign but experiences a substantial reduction in magnitude compared to regressions in Table 3. Apparently, IT contributes positively to productivity of manufacturing firms insofar as it enables them to change their internal production processes, structures, and/or boundaries. Beyond these change-stimulating effects, IT does not show significant productivity effects in manufacturing. In services, though, IT effects are not limited to IT-induced change initiatives. Only part of the productivity effect of IT is transformed to the organization through the change channels. In line with the earlier findings of this study, such interactions do not exist between the firm’s non-IT capital and organizational changes; the output elasticity of non-IT capital does not experience a serious decline if endogeneity is taken into account. Regression (10) also shows that different configurations of change practices behave differently in the manufacturing and services sectors, except for process and boundary changes (alone: Pr(1,0,1) or combined with structure changes: Pr(1,1,1)) that exert a significantly positive, direct effect on TFP.

An explanation for the differing roles of IT in manufacturing versus services has to do with the nature of common tasks and processes in these two sectors. Computers do not directly compete with tasks that involve high levels of abstraction and/or analytics. However, they can aid the productivity of these sorts of tasks by speeding up their execution. On the other hand, computers directly affect routine, repetitive tasks. In this respect, computers can dramatically change or replace for occupations that are vulnerable to automation or mechanization (e.g. assembly-line workers). The first type of processes and occupations are more common in services while the second type is more dominant in manufacturing (Acemoglu and Autor 2011).

Regression (11) extends regression (10) with interactions between capital inputs and different configurations of organizational change. Conventional capital exhibits a substitutability relationship with most OC arrangements, except when only process changes are present (Pr(1,0,0)*Ln(NIT)) or when, in services, structure and boundary changes jointly occur (Pr(0,1,1)*Ln(NIT)). In other instances, the interactions are either negative or insignificant. IT capital exhibits complementarity in services when all types of organizational change co-exist (Pr(1,1,1)*Ln(IT)), while it shows substitutability when only structure and boundary changes happen (Pr(0,1,1)*Ln(IT)). In manufacturing, we cannot observe any significant interaction between IT and OC.

There are considerable differences between the results of the two-stage approach and those of the systems method, in particular when IT capital is concerned. The synergies, complementarity effects and clustering patterns are less visible when we explicitly account for the endogeneity of organizational change in the estimations. Furthermore, the productivity effects of IT disappear or significantly diminish when IT-enabled change is incorporated in modeling the IT value creation process. This means that a significant part of the productivity effects normally attributed to IT itself are indeed contributions from other practices and policies of the firm that are in turn provoked by IT. This highlights the importance of mediating factors when examining IT performance payoffs (Zand and van Beers 2010). The findings of the two-stage method underscore the salience of incorporating endogeneity issues in future IT business value studies.

6. Discussion of Results

6.1. Hypothesis 1: IT-OCP complementarity

Hypothesis 1 postulates a complementarity relationship between IT resources and process changes of the firm. Regression (3) in Table 3 does not support H1 since a negative (still insignificant) impact from cluster (1001) on labor productivity is found. However, in the same regression, process changes become effective if they are combined with other types of organizational change. Combinations of process and boundary changes or process and structure changes together with high IT intensity lead to a positive contribution to productivity (cluster (1011) and (1101) respectively). The combination of the three types of change plus high IT intensity (cluster (1111)) also leads to a positive impact (in case of manufacturing, the effect is insignificant).

Looking at pairwise relationships, the formal tests in Table 4 confirm significant complementarity between IT and OCP. The results of the two-stage approach resemble these findings too. As regression (10) in Table 6 reveals, IT-enabled process changes only lead to a positive productivity impact if they go together with boundary or boundary and structure changes (Pr(1,0,1) and Pr(1,1,1)). The effect of process changes alone is negative, especially in case of services (Pr(1,0,0)). Regression (11) reports a significant positive interaction only when process changes are joined with structure changes (Pr(1,1,0)*ln(IT)) or, in case of services, simultaneously with both structure and boundary changes(Pr(1,1,1,)*ln(IT)).

Overall, we conclude that Hypothesis 1 is rejected in its simplest form when process changes are the only type of occurring change in the firm. If process changes are combined with other types of change, the complementarities with IT become observable and hence the hypothesis cannot be rejected. The act of combining process changes with other types of change is a requirement more necessary for the services than for the manufacturing sector.

6.2. Hypothesis 2: IT-OCS complementarity

Based on the clustering approach reported in regression (3), we observe that structural changes accompanied by high levels of IT intensity do not lead to a significantly positive impact on labor productivity unless they are combined with boundary changes (cluster (0111), for services), process changes (cluster (1101), the whole sample), or process and boundary changes together (cluster (1111), for services). This finding is in line with the conclusion that different dimensions of organizational change do not seem to act independently but rather in coherent and connected sets of specific practices. An interesting result from Table 3 is the significant negative effect on productivity from the combination of structure and boundary changes and high levels of IT intensity (cluster (0111)) in the manufacturing sector. This is due to a substitutability relationship between OCS and OCB in manufacturing firms.

Results of formal tests following the systems approach in Table 4 lend support to a complementarity relationship between OCS and IT. Looking at the cross-sectoral differences, the evidence for complementarity is sharper for the services. The results of the two-stage approach in Table 6 reveals that IT-enabled structural changes contribute to productivity growth either alone (Pr(0,1,0), for manufacturing) or when they are combined with boundary changes (Pr(0,1,1), for services) or boundary and process changes (Pr(1,1,1), for both manufacturing and services). As to the interactions in regression (11), no clear-cut conclusion can be derived. In the manufacturing sector, we cannot observe any significant interactions between IT and structure changes when the change-inducing effects of IT have already been accounted for. In services, we observe a negative interaction if structure and boundary changes coexist (Pr(0,1,1)*ln(IT)) and a positive one if process, structure and boundary changes occur simultaneously (Pr(1,1,1)*ln(IT)).

Overall, the findings support Hypothesis 2. If structure changes are considered in isolation, the evidence is stronger for manufacturing. When they are analyzed collectively with other types of OC or when the enabling role of IT is explicitly taken into account, the evidence is more conclusive for services. Two possible explanations are valid. First, major structural changes in the manufacturing sector seem to have a strong technological driver while, in the services sector, other factors such as market or competitive forces seem to drive structural changes. Second, manufacturing firms rely more than services firms on physical materials, mechanical machineries and building structures, which are more physically bounded and rigid compared to human and knowledge capital. The less flexible and adaptable structure of manufacturing firms makes it harder for them to combine structural changes with other types of change to achieve performance improvements in the short term. Manufacturing firms need more time (than the average 18-month time-lag observable in our sample) to be able to translate their complex change efforts to positive productivity effects. We leave this issue open for future investigation.

6.3.Hypothesis 3: IT-OCB complementarity

Table 3 substantiates complementarity between IT and OCB. High investments in IT and changes in boundaries of the firm lead to productivity improvement when, on top of boundary changes, structure changes are present (cluster (0111), for services), process changes are present (cluster (1011)) or both structure and process changes are present (cluster (1111), for services). The complementarity relationship between IT and OCB in the manufacturing sector does not meet all the inequality restrictions required for a decisive test result at 5% or 10% significance level as shown in Table 4. The complementarity evidence, though, remains significantly strong for the services subsample.

The findings in Table 6 also favor IT-OCB complementarity. IT-enabled boundary changes lead to productivity growth in services without respect to the presence or absence of other change practices (Pr(0,0,1), Pr(0,1,1), Pr(1,0,1), and Pr(1,1,1)). In manufacturing, though, boundary changes need to be combined with either process or process and structure changes (Pr(1,0,1) and Pr(1,1,1), respectively). Under other circumstances, the contribution of boundary changes to productivity is insignificant or negative (Pr(0,1,1) and Pr(0,0,1), respectively). Interactions with IT capital in regression (11) produce interesting results. Boundary changes increase the output elasticity of IT only when they occur alone or, in case of services, in combination with both process and structure changes. When they are joined with either process or structure changes, a negative or insignificant effect on IT elasticity is observed (Pr(0,1,1)*ln(IT) and Pr(1,0,1)*ln(IT)).

Overall, the results do not reject Hypothesis 3 under certain configurations of boundary changes with other types of OC. The clustering patterns are stronger for the services than for the manufacturing sectors of the economy. This might be due to higher importance of marketing innovation, service quality, and long-term relationship-building and the significant role of IT to facilitate these aspects in the services sector, where a bigger portion of the firms' revenues tend to come from satisfied, returning clients rather than new customers.

7. Conclusions and Recommendations for Future Research

7.1. Conclusions

The main findings of this research can be summarized as follow. First, IT exhibits a marginal productivity of as large as eight times that of ordinary capital. Firms in the services sectors of the economy enjoy higher marginal products of IT (almost two times) than their manufacturing counterparts. Second, organizational changes contribute to labor productivity of the firm if combined with proper levels of technology investments, at least as high as the industry average. Third, structure changes are found to be relatively more important for manufacturing firms while boundary changes are more relevant for services. Process changes are of similar importance for both manufacturing and services firms. Different dimensions of change have divergent (potential) effects on productivity and hence combining them into a single OC indicator (as in a number of previous studies) can obscure the inefficiencies associated with specific change configurations (especially if inter-sectoral differences are concerned) and may lead to misleading results. Fourth, we discover significantly negative interactions, in the form of substitutability relationships, between the conventional (non-IT) type of capital and OC efforts of the firm. This highlights the hampering or decelerating effects of conventional capital that is typically characterized as (quasi-)fixed assets with low degrees of functional flexibility, structural adaptability, and reusability in diverse application domains. This sheds light on the fundamental differences between IT and non-IT capital under change conditions and how they interact with change initiatives of the firm. The hindering effects of non-IT capital are more evident in services and in case of structure and boundary changes (and less process changes). Fifth, IT is found to have a dual role with regard to organizational change. In addition to complementing or supporting the change initiatives of the firm, IT also stimulates or initiates certain types of change (in particular, structure and boundary changes). These subsequent changes and investments in organizational capital explain a major part of the performance effects of IT. Sixth, our analysis reveals that the primary role of IT depends on the nature of the firm. For manufacturing firms, IT plays more the role of a change originator while for services firms it mainly plays the role of a change complement. This suggests that different types of IT applications might be more productive in different industrial contexts, partly depending on the degree of routinization and mechanization ofbusiness processes and functional tasks supported by IT. Finally, this research documents complex dynamics among different types of organizational change. IT-enabled process changes typically lead to performance improvements only when they are combined with structure, boundary, or both structure and boundary changes. Seemingly, technology-driven process changes do not lead to significant effects unless they also create fundamental changes in the (internal or external) structural elements of the firm. The necessity to combine different types of change at the same time to attain a positive outcome is more relevant for the services than the manufacturing sector.

7.2. Recommendations for future research

The present research raises important questions, each of which opens up new doors for future research in different directions. In this study, organizational change is specified through a multidimensional measure, encompassing the three primary dimensions of change. However, individual dimensions are measured through a set of dichotomous variables. Further information about the intensity of different types of change or their relative importance can enhance our understanding of the relevant phenomena. Nevertheless, it is hard to measure concepts like organizational change in an objective, quantitative manner, especially when most of the effects and consequences have an intangible, qualitative nature. Perhaps, an estimate of the total amount of related (opportunity) costs associated with a change initiative over its entire life cycle or an estimate of the number of human agents that are, directly or indirectly, involved in implementing and sustaining a change project can be considered as good indicators for quantifying OC.

Another interesting avenue for future research is a thorough analysis of the underlying dynamics behind different types of technology-driven change inside or between companies of different activity type. What is specific about manufacturing or service firms that makes IT more an enabler or supporter of change in them? Why do process changes typically need to be combined with structure or boundary changes to result in performance improvements? Why are structure changes more important for manufacturing and boundary changes for services firms? These questions can also be investigated at lower levels of sectoral aggregation to explore intra-sector differences within manufacturing and services sectors.

Some industries, most importantly the financial sector (including banking, insurance and pension funds) are lacking in our data. As the financial sector is a service-innovative sector and an intensive user of IT, we expect a sharper difference between the services and manufacturing sectors in terms of the level of IT payoffs and intensity of complementarities if the financial sector is included. Another challenging arena for future research concerns the study of time-lag effects. It deserves a separate study on how the complementarity effects and clustering patterns evolve over time. How do dynamics among different dimensions of change as well as interplays between technological and non-technological aspects of the firm develop over longer periods of time? Are the time-lag effects more relevant for manufacturing or services firms? Do time-lags act similarly for different types of change? These questions are a part of our future research agenda.

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