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Methodological Insights From two Experimental Studies Into Complementarities of Productive IT use

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Abstract: Numerous studies have attempted to determine factors that condition the IT-enabled productivity of information workers but have not yet arrived at a comprehensive conclusion. A so-called complementarity systems approach has been proposed recently, holding that a number of factors need to be managed in a deliberately synchronized manner in order to generate productivity gains from such workers. However, this proposal does not provide specifications for how such synchronization must be conducted and researched. To remedy this gap, this research conducts two parallel and differently designed studies: a longitudinal quasi-randomized field experiment and a well-controlled online experiment. Regarded jointly, each study offers insights into the investigated phenomenon that the other does not, indicating that both studies complement each other. In particular, these two different research approaches to study the complementarities of productive IT use help us to establish how further research design should be developed to investigate individual productivity when a new, more aligned IT system in a company is used together with complementary factors. Moreover, the results from both studies jointly demonstrate that a mandatory context of IT use might provide better access to individuals with both adaptive and innovative cognitive styles than a voluntary working environment. Finally, both studies demonstrate that more detailed research is needed to understand how the productivity of individuals differs when inappropriate cognitive styles are included in complementarity set-ups. Therefore, the two studies offer new insights into the interplay between the studied factors that condition the productivity of information workers and show the importance of analysing a complex phenomenon with multiple, different, and complementary research designs, as each design has inherent conditions with opportunities and limitations, in order to reveal characteristics about the phenomenon being investigated.

Keywords: complementarity systems approach, individual productivity, information worker, methodological insights, online experiment, quasi-randomized field experiment

1. Introduction

Effective use of new information technology (IT), including IT systems that support a specific kind of work process, has become critically important for modern companies. Although companies invest heavily in new IT systems, frequent decisions about acquiring or using new IT are based on executives’ speculation rather than on consistent knowledge about IT impacts (Tallon, 2014; Nielsen and Persson, 2017). Current literature demonstrates that in order to obtain a productivity increase from IT use, it is necessary to focus on a set of complementary factors that have to be synchronized with new IT systems (Brynjolfsson and Milgrom, 2013; Jain and Kanungo, 2016). However, the literature is less certain about how to study these complementary factors at the level of an individual so as to increase IT-enabled productivity. Studying complementarities is challenging as unlike conventional studies with few variables, where independent variables are assumed independent of each other and offer a linear cause-effect relation to the dependent variables, the complementarity approach recognises the complexity of reality where a set of factors interacting with each other to generate effects on one or several dependent variables (Ennen and Richter, 2010).

In this paper, we present methodological insights from two parallel and differently designed experimental studies that were conducted independently to investigate configurations of complementary factors that influence individual IT-enabled productivity of information workers. We stress, however, that we do not discuss the detailed settings and findings from each study, we provide some background and results for each study, but our key focus is on the key methodological insights obtained from two studies. Studying the same phenomenon using two different research approaches not only helps us to uncover new configurations of complementary factors but also provides us with new methodological insights that neither of these two approaches could offer on its own.

2. Background and formulated complementarity set-ups

We applied the complementarity systems approach (Milgrom and Roberts, 1995; Ennen and Richter, 2010) which investigates the impact of a system of multiple factors on performance outcomes to study complementary factors in a situation when a new, more aligned IT system is introduced and used in a company. An aligned IT
system is defined as that which offers information and information-processing functionality that is adjusted and tuned to support specific work activities within a specific kind of work process.

In general, individual productivity of an information worker is conceived as a function of a single worker, IT tool used by the worker, a task conducted and contextual settings of the worker, i.e. processes that govern the interactions among the individual, task and IT tool in order to complete tasks (Hopp, Iravani and Liu, 2009). Therefore, based on these premises and the systems approach of complementarity theory, we formulated two complementarity set-ups in which the following factors fit each other in a particular manner: adaptive/innovative cognitive style, since human cognition is the main act of information processing by information worker (Kirton, 1976, 2003), the structural complexity of the operational process (MacCormack, Verganti and Iansiti, 2001; Weber and Wild, 2005), training activities, incentives, and decision-making structure (Amabile, 1996; Ryan and Deci, 2000; Baer, Oldham and Cummings, 2003; Sense, 2007; Bloom and van Reenen, 2011). These factors were linked together into one greater system of factors that complemented each other, in which each factor was assumed to hold a binary value set. This provided a foundation for the formulation of the two key complementarity set-ups that were subjected to empirical tests (Table 1).

Table 1: Summary of predicting complementarity factors and their value range

<table>
<thead>
<tr>
<th>Predicting complementarity set-ups and factors</th>
<th>Value range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complementarity set-up</td>
<td>Stable</td>
</tr>
<tr>
<td>Cognitive style</td>
<td>Adaptive</td>
</tr>
<tr>
<td>Work process</td>
<td>Stiff</td>
</tr>
<tr>
<td>Training mode</td>
<td>Push</td>
</tr>
<tr>
<td>Motivation mode</td>
<td>Exogenous</td>
</tr>
<tr>
<td>Decision-making mode</td>
<td>High centralization</td>
</tr>
<tr>
<td></td>
<td>Dynamic</td>
</tr>
<tr>
<td></td>
<td>Innovative</td>
</tr>
<tr>
<td></td>
<td>Flexible</td>
</tr>
<tr>
<td></td>
<td>Pull</td>
</tr>
<tr>
<td></td>
<td>Endogenous</td>
</tr>
<tr>
<td></td>
<td>High decentralization</td>
</tr>
</tbody>
</table>

Therefore, we expect that (i) individuals with adaptive cognitive style generate higher productivity when matched with a ‘stable’ complementarity set-up that includes a stiff operating process, push mode training in work technology, exogenous incentives, and centralized decision-making compared to other configurations of these factors when a more aligned IT system is used. In contrast, we expect that (ii) individuals with innovative cognitive style generate higher productivity when matched with a ‘dynamic’ complementarity set-up that includes a flexible operating process, a combination of minor upfront mandatory training with optional on-demand training in work technology, endogenous incentives, and decentralized decision-making compared to other configurations of these factors when a more aligned IT system is used. Our contribution to the literature is that by applying the systems approach of complementarity theory, we propose new configurations of complementary factors that have been established and explored independently by other studies mentioned in this section.

3. Methodology

The research strategy was based on two independent studies: a longitudinal quasi-randomized field experiment (Study A) in which we investigated the operational productivity of sales representatives and an online experiment of software programmer productivity (Study B). The choice of research methodology and its rationale is explained in more detail below.

First, since we needed to study whether changes in operational set-ups cause productivity differences owing to different configurations of complementary factors, the experimental design was appropriate for testing the formulated complementarity set-ups. Second, in order to study the impact of IT use on individual productivity it was necessary to capture productivity data over a period of time and to take into account the time-lag effect on productivity gains from IT use (Brynjolfsson, 1993; Devaraj and Kohli, 2003). Therefore, a longitudinal research approach is important when studying complementarities of productive IT use to demonstrate their effect over time. These two premises form a foundation for the longitudinal field experiment, which enables analysis of a targeted phenomenon in its natural setting without artificially introducing confounding variables as well as capture of the effect of intervention over time (Hassett and Paavilainen-Msntymski, 2013). Third, in addition to the time-lag effect, we needed to provide better control over complementarities and their impact on IT-enabled productivity that could be achieved by conducting well-controlled laboratory experiments. However, recent online experiments have become even more popular than laboratory experiments, since they reduce the influence of experimenters’ expectations on participants’ behaviour, provide access to wider populations, and increase the uniformity of the experimental procedure across participants (Reips, 2002). Therefore, both a
longitudinal field experiment and a well-controlled online experiment responded to the complementarity set-ups tested in this research. Finally, we chose two information-intensive professions—sales representatives and software programmers—as appropriate examples of information workers (North and Gueldenberg, 2011) who require cognitive skills to process information which is an input and output of the production process and use non-trivial IT systems as their main production tool. Thus, two independent studies are appropriate for in-depth exploration of complementarity configurations, because we can identify whether the emerged patterns in one study are confirmed in the other, and thereby, can aspire to stable results. The set-up characterization of Study A and Study B is presented in Table 2.

Table 2: Set-up characterization of Study A and Study B

<table>
<thead>
<tr>
<th>Key characteristics</th>
<th>Study A</th>
<th>Study B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of study</td>
<td>Longitudinal quasi-randomized field experiment</td>
<td>Web-based online experiment</td>
</tr>
<tr>
<td>Focus</td>
<td>Productivity of sales representatives</td>
<td>Productivity of software programmers</td>
</tr>
<tr>
<td>Data collected</td>
<td>Data were collected over a period of 5.5 years: January 2012 – June 2017 (9 quarters pre-change and 13 quarters post-change)</td>
<td>The online experiment was available online for 4 months (October 2015 – January 2016)</td>
</tr>
<tr>
<td>Context</td>
<td>Nordic affiliate of a global pharmaceutical corporation</td>
<td>Dedicated website for experiment; subjects recruited globally through online staffing firms</td>
</tr>
<tr>
<td>Metric</td>
<td>Number of sales calls and products sold in relation to the duration of time worked by an individual</td>
<td>Programming time and quality (completeness and correctness) of the product developed</td>
</tr>
<tr>
<td>Subject participation</td>
<td>Mandatory participation as part of regular work tasks</td>
<td>Voluntary participation incentivized with minor payment</td>
</tr>
<tr>
<td>No. of subjects investigated</td>
<td>91 of which 31 are innovators and 60 are adaptors</td>
<td>113, of which 110 are innovators and 3 are adaptors</td>
</tr>
<tr>
<td>Study design</td>
<td>4-factor configurations distributed over 16 business units (4 products; 4 counties): Design 1: no change; control group Design 2: new IT system only Design 3: new IT system, new sales process Design 4: all factors; new IT system, new process, training and education mode, incentives, and decision-making authority</td>
<td>3 sessions/assignments for software programming for each subject. Session 1: simple IT-tool support Session 2: advanced IT-tool support and all factors Session 3: advanced IT-tool support and all factors Each session lasted between 20 minutes and 1 hour</td>
</tr>
<tr>
<td>Subjects’ context allocation</td>
<td>Adaptors in a ‘stable’ complementarity set-up Innovators in a ‘dynamic’ complementarity set-up</td>
<td>Innovators in ‘stable’ and ‘dynamic’ complementarity set-ups</td>
</tr>
<tr>
<td>Data analysis method</td>
<td>Difference-in-difference</td>
<td>Repeated measures analysis of variance</td>
</tr>
<tr>
<td>Study deviation</td>
<td>Subjects’ allocation did not allow us to identify productivity of adaptors in ‘dynamic’ and innovators in ‘stable’ complementarity set-ups</td>
<td>The study succeeded in attracting mostly innovators</td>
</tr>
</tbody>
</table>

Study A was conducted in a Nordic affiliate of a global pharmaceutical company that is among the top 50 largest life-science corporations in the world. The affiliate received a new sales-support IT system that was designed to facilitate sales representatives’ daily work at the end of April 2014. This IT system was installed in the company with four different designs (operational–organizational configurations of complementary factors) to study their impact on individual productivity of sales representatives. These four designs were allocated into a four-by-four operational structure (with four different products, A, B, C, and D, and four different markets, Denmark, Finland, Norway, and Sweden) to neutralize the influence of the product as well as the market over sales performance. Participants in the first group (Design 1) acted as a control group and operated in the way the whole company operated prior to the introduction of the new IT system. Participants in the second group (Design 2) received the new IT system, yet remained with the same operational set-up as prior to the change. Participants in the third group (Design 3) received the new IT system together with a new and specific type of sales process (sales representatives were not obliged to follow all operational steps in the new process). In the fourth group (Design 4), the ‘full’ or comprehensive set of IT complementarities was assumed, based on the developed complementarity set-ups. Productivity data (the number of sales calls and products sold relative to the length
of time worked by an individual) were collected for every quarter over a period of 5.5 years (9 quarters before and 13 quarters after the introduction of the new IT system).

In Study B, we used a dedicated website to test whether a set of matched complementary factors can indeed affect productivity in relation to adaptive/innovative cognitive style when a more aligned IT system was implemented and used. We expected that adaptors rather than innovators have productivity advantages when a more aligned IT system is used together with a ‘stable’ complementarity set-up. In contrast to adaptors, we expected that innovators would gain productivity advantages when a more aligned IT system is used together with a ‘dynamic’ complementarity set-up. The experiment consisted of three sessions/assignments. In the first session, in order to establish a benchmark, participants developed a software application using a text editor, which represents an existing IT system in a company. In the second session, an advanced IT system, Cloud9, an online integrated development environment that provides comprehensive facilities for software development introduced in a synchronized manner with both cognitive styles and complementarity set-ups. The third session was designed to take into account a learning-curve effect (Womer, 1984; McLeod, Clark and Dietrich, 2008). This session also included the advanced IT tool and complementarities of the second session. Each session had identical time frames (approximately 20 minutes to 1 hour) and a slight variation of assignments, yet with an equal level of complexity. The time taken by the subjects to complete each session was used to characterize a quantitative dimension of the productivity metric. In addition, as a measure of productivity, we used completeness (how many of the functional requirements were completed) and correctness (how well the functional requirements were implemented) of the application developed to evaluate the quality of the developed product.

4. Results

Table 3 summarizes the characterization of the key results from both studies that together offer insights into the methodology of the investigated phenomenon about complementarities and IT-enabled productivity.

<table>
<thead>
<tr>
<th>Key characteristics</th>
<th>Study A</th>
<th>Study B</th>
</tr>
</thead>
</table>
| Study results       | Design 1: no productivity change  
                     Design 2: decreased productivity  
                     Design 3: decreased productivity  
                     Design 4: increased productivity | Session 1: Innovators in a ‘dynamic’ context worked faster yet generated lower quality of the product developed, while innovators in a ‘stable’ context worked slower yet generated higher quality of the product.  
                     Session 2: Innovators involved in a ‘dynamic’ context had a greater change in completion time when they learned a new IT system.  
                     Session 3: Innovators involved in a ‘dynamic’ context set-up learned a new IT system faster than did innovators involved in a ‘stable’ context |
| Key conclusions     | Synchronization of complementarities conditions productivity of information workers. There is a learning effect from the changes made for productivity gains that takes no longer than 3 months | In the first and third sessions, innovators involved in a ‘dynamic’ context worked faster, yet with significantly lower quality than did innovators involved in a ‘stable’ context. A learning effect is achieved from two sessions of the new IT system and complementarity set-up versus the old IT system and complementarity set-up. However, the study suggests that the learning effect has just started |
| Key methodological insights | Complementarity set-ups might have both positive and negative productivity impacts. With productivity data provided on a quarterly basis, it is difficult to identify the learning effects of the adoption of a new IT system and work practices. Further research is needed to understand how the productivity of individuals with different cognitive styles is affected by non-matched complementarity set-ups | Future research has to take into account whether a work environment is mandatory or voluntary to collect data on individuals with both cognitive styles. More sessions of the experiment are needed to achieve saturation in productivity scores before and after use of a new, more aligned IT system is stabilized. Both performance metrics (time and quality) have to be monitored closely to understand the impact of complementarity set-ups |


In Study A, the final sample for the analysis comprised 91 participants located almost equally in each design. The average age was 39 years old and most participants had a Master (52%) and Bachelor degree (42%). On average, participants had 5 years of experience in the company, 7 years of experience in sales and 10 years of experience in the sales industry. By using Kirton’s inventory of adoption-innovation (Kirton, 1976), we identified that out of 91 subjects 31 were innovators and 60 were adaptors and in particular in Design 4, out of 27 subjects 7 were innovators and 20 adaptors. In this study, we expected that sales representatives involved in Design 4 with a full set of complementarities would generate greater productivity than sales representatives involved in Design 1 without operational change, Design 2 with structured partial change, and Design 3 with semi-structured partial change. Consistent with our expectation, the obtained results in Study A showed a positive and statistically significant effect of complementarities on individual IT-enabled productivity of sales representatives. In particular, the results indicated that the productivity of sales representatives involved in the design with the full complementarity set-up increased significantly after the implementation of changes compared to the productivity of sales representatives involved in designs with no or only partial complementarity set-ups. In addition, our results showed that when the more aligned IT system was used without complementarities, the opposite (negative) effect could occur. Moreover, the results showed that limited or incorrectly assumed complementarity factors might negatively affect individual IT-enabled productivity. These results are in line with those of previous studies (Roberts, 2007; Poon, Davis and Choi, 2009) which demonstrated that some configurations of factors might generate positive performance while others might generate negative performance. Moreover, the study demonstrated that the learning effect from the changes made for productivity gains does not take more than 3 months.

In Study B, we were able to collect data only for software programmers with innovative cognitive style. Out of 113 participants that completed the experiment, only 3 have had an adaptive cognitive style and were excluded from the analysis. The majority of participants were from Europe (47%), Asia (23%) and North America (14%). The average age was 28 years old and 80% male gender. The largest number of participants had a Bachelor degree (39.8%), up to five (34.1%) and ten years of programming experience (30.7%). In Study B, the results demonstrated that when completing the first session with a less aligned IT system, time scores were significantly different for innovators who were involved in ‘stable’ and ‘dynamic’ complementarity set-ups (42 minutes vs. 33 minutes, \( p = 0.009 \)). Quality scores were significantly different for innovators involved in ‘stable’ and ‘dynamic’ complementarity set-ups (77% vs. 63%, \( p = 0.006 \)). As we expected when completing the second session with a more aligned IT system, time scores increased for both groups. However, average session completion time increased by 7 minutes (16%) for innovators involved in a ‘stable’ complementarity set-up and by 18 (54%) minutes for innovators involved in a ‘dynamic’ complementarity set-up compared to the baseline. Nonetheless, the difference between time scores for both groups of participants became insignificant. Quality scores remained similar to the first session and the difference between these scores was statistically significant (75% vs. 62%, \( p = 0.002 \) respectively). The results demonstrate that in comparison to the second session, in the third session, time scores decreased for the participants involved in both complementarity set-ups. The average session completion time decreased by 2 minutes (4%) for innovators involved in a ‘stable’ complementarity set-up and by 6 minutes (12%) for innovators involved in a ‘dynamic’ complementarity set-up. Quality scores did not change significantly in comparison to the second assignment (73% vs. 61%, respectively, \( p = 0.032 \)). Overall, besides the results that demonstrate that individual productivity of innovators differs in relation to complementarities, the study offers several insights about the design of similar experiments.

5. Methodological insights

In order to generate insights into the same target phenomenon, in our case complementarities of productive IT use, two very different research approaches have been applied. This research strategy helped us to produce new knowledge that neither of the two research approaches was able to produce individually. Below, we summarize the key methodological insights from both studies regarded together, which can be taken into account by future research in the field of complementarities and individual IT-enabled productivity.

First, the obtained results from Study A showed that complementarities introduced together with a more aligned IT system positively affected the productivity of employees. These results provide strong support for the systems approach of complementarity theory (Ennen and Richter, 2010) which investigates the impact of a system of multiple factors on performance outcomes. In addition, these results add new and unique configurations of complementary factors for individual IT-enabled productivity studies (Athey and Stern, 2002; Autor, Levy and Murnane, 2003). However, although the data in Study A showed that it took around 3 months for individuals to
learn the new IT system, this study did not show how exactly individuals with different cognitive styles learned and mastered this IT system. At the same time, Study B demonstrated that a learning effect was achieved from two sessions of use of the new IT system. However, the study demonstrated that the learning effect had only just emerged. Therefore, the results from both studies regarded jointly showed that the learning effect of a new IT system requires more than two sessions, but less than 3 months of daily use. This requires further research to understand how the learning effect is achieved.

Second, Study A was conducted in real work settings, meaning that information workers had to partake in the study, as it was part of their conventional work and employment held. On the other hand, in Study B, participation in the experiment was voluntary. This voluntary-based approach merely attracted individuals with innovative cognitive style. One plausible conclusion is that in order to study both cognitive styles in the same context, a mandatory context has to be used, as voluntary participation might fail to attract both cognitive styles. On the other hand, an online environment as a working environment could mostly attract individuals with innovative cognitive style, rather than individuals with adaptive cognitive style. For example, internet-based jobs are characterized as temporary and rapidly changing (Sadler, Robertson and Kan, 2009), which is more suitable for innovative individuals. This fit between cognitive style and working environment seems to match findings from previous studies (Kirton, 2003; Chilton, Hardgrave and Armstrong, 2005), suggesting that a rapidly changing environment requires individuals with innovative cognitive style. Nonetheless, more research is needed, since online work environments have not been researched extensively.

Third, Study A showed that the productivity of a particular cognitive style increased in a particular complementarity set-up, that is, adaptors in a ‘stable’ complementarity set-up and innovators in a ‘dynamic’ complementarity set-up. However, Study A did not show whether a cognitive style could perform differently in the non-matched complementarity set-up, all else being the same. This implies that further detailed research is needed to understand how the productivity of individuals with different cognitive styles is affected by other complementarity set-ups. Study B showed that individuals with innovative cognitive style performed differently in different complementarity set-ups (stable vs. dynamic). For example, innovators involved in a ‘dynamic’ complementarity set-up spent, on average, much less time performing the first assignment. However, on average, the quality was higher for applications developed by innovators involved in a ‘stable’ complementarity set-up. The manner in which both groups of participants learned a more aligned IT system was also quite different. Innovators involved in a ‘dynamic’ complementarity set-up had a greater change in completion time when learning to use the more aligned IT system first. However, the learning pattern was lower than that of innovators involved in a ‘stable’ complementarity set-up. These results imply that both performance metrics (time and quality) have to be monitored closely in future research to understand the impact of complementarity set-ups.

In summary, our empirical investigations demonstrated that in order to explore complementarities and their effect on IT-enabled productivity, multiple research designs are required to address the limitations of each design on its own. For example, although we were able to take into account the effect of complementarities on IT-enabled productivity over time in the first study, data collected quarterly did not allow us to identify the learning effects of adopting and using the new IT system. On the other hand, in the second study we collected data from only three sessions (two of which were related to use of a new IT system), which was not enough to identify the learning effect. Therefore, since more runs are required to establish saturation with old, less aligned IT systems as well as new, more aligned IT systems, time-series design of the experiment would be appropriate. This design would enable the assessment of productivity prior to and after the introduction of a new IT system and identification of the existence of complementarity effects on IT-enabled productivity within a temporal sequence of events.

References

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