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Coordination costs and ICT investments: an economic analysis

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Abstract This study analyzes how attributes of economic activities are related to information and communication technology (ICT) investments. Since ICT can reduce coordination costs by affecting information processing, communication, delays and errors, coordination cost attributes of the activities can explain these investments. The study focuses on four coordination cost attributes that are the frequency and complexity of the activity and the timeliness and accuracy required in the activity. It introduces the timeliness rate and the accuracy loss. When the expected net present value of the activities and ICT investments has exactly one viable maximum, the ICT investments are increasing with frequency, timeliness and accuracy. Complexity decreases these investments for sure if the marginal costs of the information processing and communication, the marginal duration of the activity and the marginal probability of the erroneous outcome are increasing with complexity.

Keywords Coordination costs · Economics of information and communication technology (ICT) · Investments · Transaction cost economics

1 Introduction

Information and communication technologies (ICT) have had considerable effects on how firms do business and organize their activities [4]. A number of empirical studies have documented the significant impacts of ICT on economic performance [9]. The essence of coordination involves information processing and communication [20]. ICT can reduce the costs of information processing and communication, save

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time and avoid errors. For example, electronic data interchange has yielded savings in document processing and transmission [23], increased speed of transactions and decreased errors in transactions [22, 26]. Although ICT has commonly held as a coordination tool, attributes of economic activities that facilitate or inhibit investments in ICT have been scarcely studied in theoretical terms [1, 18].

What kinds of activities benefit most from ICT is not completely clear. Since both off-premises and on-premises ICT require resources, it is important to study carefully which activities should be supported by ICT. The implementation and operation of ICT demand investments in computer hardware, software development and systems, communication equipment and Internet access, training of the users and maintenance of the information systems (IS). In fact, ICT does not produce any benefits if its implementation or operation is very sloppy.

Information theory and information economics are two relevant theoretical approaches to characteristics of information [29]. According to Ciborra [7], transaction cost economics provides a potential approach for studying the utilization of ICT. It has been employed to explain changes in industry structures resulting from ICT investments [1]. Electronic commerce has received main attention in these studies [18]. For example, business-to-business (B2B) electronic commerce has found to reduce transaction costs [14]. There are also arguments that transaction costs often increase as a consequence of ICT [8].

This study does not focus on characteristics of information but on attributes of economic activities. Building on transaction cost economics [21, 30], IS research [20, 29] and accounting research [13], the study analyzes how the frequency and complexity of the activity and the timeliness and accuracy required in the activity as coordination cost attributes explain the ICT investments. In this study, an economic activity means a set of actions and interactions that are needed to produce a given outcome. An agent processes the information in the actions and communicates the information with other agents in the interactions. The current study formalizes a theoretical model which complements empirical findings presented in some previous studies [6, 24, 28]. The purpose of this model is to justify the ICT investments by contrasting the world with coordination costs to the perfect world. Ballou et al. [2] have also modeled timeliness, accuracy and costs in the context of ICT but their focus is on attributes of information products.

The study proceeds as follows. First, this study introduces coordination costs. Section 3 specifies the model. Section 4 contains the comparative statics analysis that results in four propositions. Finally, the study discusses the coordination cost attributes and presents the conclusions.

2 Coordination costs

Williamson [30] presents that asset specificity, uncertainty and *frequency* as transaction cost attributes determine the choice between the markets and firms. Asset specificity refers to investments in a location, physical asset, human asset or dedicated asset which has a much lower value in the best alternative use than in the original use.

Parametric uncertainty depends on the predictability of the modifications in the environment, while behavioral uncertainty arises because of non-disclosure, disguise or distortion of information. For a part of frequency, specialized governance structures are much easier to justify for frequent transactions than for infrequent ones. Milgrom & Roberts [21] recognize *complexity* that is the difficulty of measuring performance in the transaction and the connectedness of the transaction to other transactions. Transaction costs can be divided into motivation and coordination costs. While motivation costs are associated with incomplete and asymmetric information as well as incomplete contracts, coordination costs are the costs of processing and communicating the information that is needed to determine the price to be charged or the plan to be implemented [21]. These coordination costs also comprise the costs of delays and errors.

Direct coordination costs are the costs of processing and communicating information. The fact is that both information processing and communication take time and efforts. Radner [25] classifies the costs of decision making into the gathering, storage and manipulation of information. In addition, the transmission of information has to be taken into account when group decision making is considered. Indirect coordination costs are the costs of delays and errors. Feltham [13] categorizes the delays and errors in decision making into the reporting delays, reporting intervals, system errors and perception errors. Delays and errors cause additional uncertainty about the past events, which causes additional uncertainty about future events. Therefore, they lead to poor decisions and lost opportunities.

Of the transaction cost attributes, asset specificity and uncertainty are motivation cost attributes. They can clarify the choice between outsourcing and insourcing of ICT [19] rather than the extent of the ICT investments. Frequency and complexity can be regarded as both motivation and coordination cost attributes. Frequency of the activity is proportional to the volume of the activities. When transactions recur with higher frequency, investments in a specific mechanism are more likely recovered [30]. Malone et al. [20] suggest that complexity of the product description is the amount of information needed to specify the attributes of a product in enough detail. When complexity of the activity manifests the amount of actions and interactions, a more complex activity tends to demand more information processing and communication than a less complex activity.

Feltham [13] has introduced *timeliness* and *accuracy* as desirable characteristics of information. According to Wand & Wang [29], timeliness reflects the parity between the real-time and system states, whereas accuracy depicts the similarity between the real-world and system states. The system can be in the past state due to the delay or in the fallacious state due to the error. Timeliness and accuracy along with other items have been utilized to measure the IS success through the information quality construct [11]. Focusing on the requirements in the economic activities instead the IS success, timeliness and accuracy provide sound coordination cost attributes.

The delays and errors do not only originate from the information. Although agents have real-time real-world information, a physical or psychical reason can cause a delay or error in an activity. For example, if there is a sudden lack of proper skills or strength, the activity may become more complex and it cannot be performed as quickly or flawlessly as usual. In these situations, ICT offers very limited help. Timeliness is associated with the costs of delays. The higher the cost of the delay is, the higher is the timeliness required in the activity and the shorter should the duration of the activity be. Respectively, accuracy is related to the costs of errors. The higher the cost of the error is, the higher is the accuracy required in the activity and the smaller should the probability of the erroneous outcome be.

3 The model

The model relates frequency and complexity of an activity and timeliness and accuracy required in this activity to ICT investments. For simplicity, let the investments $i \geq 0$ cover the costs of implementation and operation of ICT, the benefits of the outcome be $B > C$, the costs of the activity be $C \geq 0$ and the interest rate be $R > 0$. Consider a group of agents which perform given activities with frequency $F > 0$. The agents can perform only one activity at a time and the activities have the time interval $\frac{1}{F}$. In the perfect world, the problem is to maximize the net present value of the activities and ICT investments

$$\max_i \{v(i|F) - i\} = \max_i \left\{ \sum_{j=0}^{\infty} \frac{B - C}{(1+R)^{\frac{j}{F}}} - i \right\} = \max_i \left\{ \frac{B - C}{1 - (1+R)^{-\frac{1}{F}}} - i \right\}. \quad (1)$$

A straightforward solution is that there is no reason for the investments $i = 0$.

Processing and communicating information in the activity has complexity $K \geq 0$. This causes the costs of the activity $c(i|K) \geq C$ such that $c(i|K)|_{K=0} = C$. The benefits of the outcome are discounted with the timeliness rate $T \geq 0$. The timeliness rate can depend on how quickly the outcome of the activity becomes obsolete or deteriorates. The delay is the duration of the activity $d(i|K) \in \left[0, \frac{1}{F}\right]$. If the activity is performed with some error, the outcome is erroneous and the accuracy loss $A \geq 0$ reduces the value of the activity. The error is dependent on the probability of the erroneous outcome $e(i|K) \in [0, 1]$.

The key assumptions are that ICT can reduce the costs of the information processing and communication $c_i(i|K) \leq 0$, the duration of the activity $d_i(i|K) \leq 0$ and the probability of the erroneous outcome $e_i(i|K) \leq 0$ when its implementation and operation are diligent. By adding the standard assumptions, ICT has diminishing effects $c_{ii}(i|K) \geq 0$, $d_{ii}(i|K) \geq 0$ and $e_{ii}(i|K) \geq 0$. Intuitively, complexity has adverse influences on information processing and communication $c_K(i|K) \geq 0$, delays $d_K(i|K) \geq 0$ and errors $e_K(i|K) \geq 0$. For example, automation of ordering activities requires ICT investments in an order-processing system to generate savings in coordination costs. Potential further savings demand the ICT investments in sales and procurement systems, next in the electronic exchange of orders and order confirmations between the order-processing and related internal systems and then in their electronic exchange with the external systems (i.e. customers' and suppliers' order-processing systems).

In the world with coordination costs, the activity has two possible outcomes. Following a cash-in-advance constraint, funds must be available for the costs of the activity and the expected accuracy loss before the activity is started. When the outcome is flawless, the value of the activity is

$$v^{\text{flawless}}\left(i|K,T,A\right)=\frac{B}{\left(1+T\right)^{d(i|K)}}-c\left(i|K\right). \tag{2}$$

Note that $v^{\text{flawless}}\left(i|K,T,A\right)\leq B-C$ for all $i\geq 0$, $K\geq 0$, $T\geq 0$ and $A\geq 0$. For the erroneous outcome, this value is

$$v^{\text{erroneous}}\left(i|K,T,A\right)=v^{\text{flawless}}\left(i|K,T,A\right)-A=\frac{B}{\left(1+T\right)^{d(i|K)}}-A-c\left(i|K\right). \tag{3}$$

Taking into account these outcomes (2–3), the problem is to maximize the expected net present value of the activities and ICT investments

$$\begin{aligned}&\max_i\left\{v\left(i|F,K,T,A\right)-i\right\}\\&=\max_i\left\{\frac{(1-e(i|K))v^{\text{flawless}}(i|K,T,A)+e(i|K)v^{\text{erroneous}}(i|K,T,A)}{1-(1+R)^{-\frac{1}{F}}}-i\right\}.\\&=\max_i\left\{\frac{B(1+T)^{-d(i|K)}-Ae(i|K)-c(i|K)}{1-(1+R)^{-\frac{1}{F}}}-i\right\}\end{aligned} \tag{4}$$

There are no coordination costs when $c\left(i|K\right)=C$, $d\left(i|K\right)=0$ and $e\left(i|K\right)=0$ for all $i\geq 0$ and $K\geq 0$. On the other hand, if $K=0$, $T=0$ and $A=0$, the coordination costs have no effects on the expected net present value and Eq. 4 is simplified to Eq. 1.

4 Analysis

Let the costs of the investments solving the problem (4) be $i^*\geq 0$. The expected present value of the activities is denoted by $v=v\left(i|F,K,T,A\right)|_{i=i^*}$ the costs of the activity by $c=c\left(i|K\right)|_{i=i^*}$, the duration of the activity by $d=d\left(i|K\right)|_{i=i^*}$ and the probability of the erroneous outcome by $e=e\left(i|K\right)|_{i=i^*}$. The investments should satisfy the feasibility constraint

$$v=\frac{B\left(1+T\right)^{-d}-Ae-c}{1-\left(1+R\right)^{-\frac{1}{F}}}>i^*, \tag{5}$$

the first-order condition

$$\begin{aligned}v_i&=-\frac{B\ln(1+T)d_i(1+T)^{-d}+Ae_i+c_i}{1-(1+R)^{-\frac{1}{F}}}\\&=\underbrace{-\frac{B\ln\left(1+T\right)d_i\left(1+T\right)^{-d}}{1-\left(1+R\right)^{-\frac{1}{F}}}}_{\geq 0}\underbrace{-\frac{Ae_i}{1-\left(1+R\right)^{-\frac{1}{F}}}}_{\geq 0}\underbrace{-\frac{c_i}{1-\left(1+R\right)^{-\frac{1}{F}}}}_{\geq 0}=1\end{aligned} \tag{6}$$

and the second-order condition

$$
\begin{aligned}
v_{ii} &= \frac{B(\ln(1+T)d_i)^2(1+T)^{-d} - B\ln(1+T)d_{ii}(1+T)^{-d} - Ae_{ii} - c_{ii}}{1-(1+R)^{-\frac{1}{F}}} \\
&= \underbrace{\frac{B\left(\ln\left(1+T\right)d_i\right)^2\left(1+T\right)^{-d}}{1-\left(1+R\right)^{-\frac{1}{F}}}}_{\geq 0} - \underbrace{\frac{B\ln\left(1+T\right)d_{ii}\left(1+T\right)^{-d}}{1-\left(1+R\right)^{-\frac{1}{F}}}}_{\leq 0} . \\
&\quad - \underbrace{\frac{Ae_{ii}}{1-\left(1+R\right)^{-\frac{1}{F}}}}_{\leq 0} - \underbrace{\frac{c_{ii}}{1-\left(1+R\right)^{-\frac{1}{F}}}}_{\leq 0} < 0
\end{aligned}
\tag{7}
$$

The feasibility constraint (5) entails that the ICT investments $i^* > 0$ are economically viable. The expected net present value has one and only one viable maximum if the ICT investments also satisfy the first-order and second-order conditions (6–7). Before the comparative statics analysis, an important observation can be presented.

Lemma 1 *The investments $i^* > 0$ resulting from the first-order condition always satisfiy the second-order condition when delays follow a constraint $\ln\left(1+T\right)d_i^2 < d_{ii}$. Information processing, communication and errors relax the constraint. If this or the feasibility constraint is not fulfilled, there should be no investments $i^* = 0$.*

$$
\begin{aligned}
B\left(\ln\left(1+T\right)d_i\right)^2\left(1+T\right)^{-d} &< B\ln\left(1+T\right)d_{ii}\left(1+T\right)^{-d} \\
&\leq B\ln\left(1+T\right)d_{ii}\left(1+T\right)^{-d} + Ae_{ii} + c_{ii}
\end{aligned}
\tag{8}
$$

The influences of delays can cause that the second-order condition is not satisfied, while information processing, communication and errors have the relaxing influences in Eq. 8. The observation is that sometimes the ICT investments do not strictly maximize the expected net present value $v_{ii}\left(i|F,K,T,A\right)|_{i=i^*} \geq 0$. When they do and fulfill the feasibility constraint, the ICT investments are justified in the world with coordination costs and enable even an activity that would be unprofitable without ICT $v\left(i|F,K,T,A\right)|_{i=0} \leq 0$.

Proposition 1 *Frequency F increases the investments i^*.*

Proof This results from

$$
\begin{aligned}
\frac{\mathrm{d}i^*}{\mathrm{d}F} &= \frac{B\ln(1+T)d_i(1+T)^{-d} + Ae_i + c_i}{v_{ii}\left(1-(1+R)^{-\frac{1}{F}}\right)^2}\frac{\ln(1+R)}{F^2}\left(1+R\right)^{-\frac{1}{F}} \\
&= -\frac{v_i\ln(1+R)}{v_{ii}F^2\left((1+R)^{\frac{1}{F}}-1\right)} \geq 0
\end{aligned}
.
\tag{9}
$$

Proposition 1 agrees with empirical evidence that transactional frequency [6, 17, 27] and process frequency [24, 28] facilitate the ICT adoption. Frequency aggregates both direct and indirect coordination costs. When an activity is more frequent, the total costs of information processing, communication, delays and errors are higher. Therefore, if one activity is more frequent than another activity and all other things are equal, the former activity should have larger ICT investments than the latter activity. □

Proposition 2 *Complexity K decreases the investments i^* when the marginal costs of the information processing and communication, the marginal duration of the activity and the marginal probability of the erroneous outcome are increasing with complexity. Otherwise, complexity can increase these investments.*

Proof Although complexity K has an ambiguous effect on the investments

$$\frac{\mathrm{d}i^*}{\mathrm{d}K} = \frac{B\ln(1+T)d_{iK}(1+T)^{-d} - B(\ln(1+T))^2 d_i d_K (1+T)^{-d} + Ae_{iK} + c_{iK}}{v_{ii}\left(1-(1+R)^{-\frac{1}{F}}\right)}$$

$$= \underbrace{\frac{B\ln(1+T)\,d_{iK}\,(1+T)^{-d}}{v_{ii}\left(1-(1+R)^{-\frac{1}{F}}\right)}}_{\lesseqgtr 0} - \underbrace{\frac{B\,(\ln(1+T))^2\,d_i d_K\,(1+T)^{-d}}{v_{ii}\left(1-(1+R)^{-\frac{1}{F}}\right)}}_{\leq 0}, \tag{10}$$

$$+ \underbrace{\frac{Ae_{iK}}{v_{ii}\left(1-(1+R)^{-\frac{1}{F}}\right)}}_{\lesseqgtr 0} + \underbrace{\frac{c_{iK}}{v_{ii}\left(1-(1+R)^{-\frac{1}{F}}\right)}}_{\lesseqgtr 0} \lesseqgtr 0$$

this effect is negative when there hold $c_{iK} \geq 0$, $d_{iK} \geq 0$ and $e_{iK} \geq 0$. Proposition 2 matches well to mixed empirical findings. Some studies have shown that product complexity has a positive effect on the ICT adaption [6, 15]. In other studies, process complexity has found to have no direct relation to this adoption [12, 24, 28]. Complexity primarily affects direct coordination costs. It can also influence indirect coordination costs by increasing the duration of the activity or the probability of the erroneous outcome. When an activity is more complex, the costs of the information processing and communication, at least, are higher. For this reason, it is suprising that the ICT investments in more complex activities should not necessarily be larger than these investments in less complex activities. One explanation is that the benefits of ICT do not outweigh its costs in the knowledge-intensive activities as they do in the routine activities [5]. On the other hand, activities can be simplified by reengineering before investing in ICT [16]. □

Proposition 3 *Timeliness T increases the investments i^*.*

Proof The timeliness rate has a positive influence on the investments

$$\frac{\mathrm{d}i^*}{\mathrm{d}T} = \frac{Bd_i(1+T)^{-d-1} - B(\ln(1+T)d_i)^2(1+T)^{-d}}{v_{ii}\left(1-(1+R)^{-\frac{1}{F}}\right)}$$

$$= \underbrace{\frac{Bd_i\,(1+T)^{-d-1}}{v_{ii}\left(1-(1+R)^{-\frac{1}{F}}\right)}}_{\geq 0} - \underbrace{\frac{B\,(\ln(1+T)\,d_i)^2\,(1+T)^{-d}}{v_{ii}\left(1-(1+R)^{-\frac{1}{F}}\right)}}_{\geq 0} \geq 0\cdot \qquad (11)$$

Proposition 3 is consistent with empirical findings. ICT improves the timeliness of information [10] and the timeliness requirements have stronger positive influences on the ICT adaption than do the accuracy requirements [24]. For example, ordering activities required the highest timeliness and had the highest necessity of B2B integration, while product design activities required the lowest timeliness and had the lowest necessity of B2B integration in the telecommunications industry [24]. Timeliness is associated with indirect coordination costs. A lack of timeliness induces idle resources due to stoppage and inventories. The timeliness rate reflects the costs of the delay by discounting the benefits of the outcome. If one activity requires higher timeliness than another activity and all other things are equal, the former activity should have larger ICT investments than the latter activity. □

Proposition 4 *Accuracy A increases the investments i^*.*

Proof For a part of the accuracy loss, it is easy to show

$$\frac{\mathrm{d}i^*}{\mathrm{d}A} = \frac{e_i}{v_{ii}\left(1-(1+R)^{-\frac{1}{F}}\right)} \geq 0. \qquad (12)$$

Proposition 4 is coherent with empirical evidence. ICT has more positive impacts on the accuracy of information than on the timeliness of information [10] and the accuracy requirements advance the ICT adoption [24]. For example, invoicing activities required the highest accuracy and the necessity of their B2B integration was very high, whereas demand forecasting activities required the lowest accuracy and this necessity was low in the telecommunications industry [24]. Accuracy is also related to indirect coordination costs. A lack of accuracy causes wasted resources due to debris and repairs. The expected accuracy loss is the costs of the error which are reduced from the value of the activity. If one activity requires higher accuracy than another activity and all other things are equal, the former should have larger ICT investments than the latter activity. □

5 Discussion

Although transaction cost economics can help in an understanding of ICT [7], traditional transaction cost attributes (i.e. asset specificity, uncertainty and frequency [30]) alone are not sufficient to explain the ICT investments. Both scientific and practical considerations call for economic analyses of relationships between coordination cost attributes of activities and ICT investments. Asset specificity and uncertainty as motivation cost attributes can clarify outsourcing and insourcing of ICT [19]. Asset-specific investments in ICT can also provide a credible commitment to coordination. However, ICT does not eliminate all parametric uncertainty. In addition, it does not remove behavioral uncertainty. ICT primarily reduces additional uncertainty which results from delays and errors. Since there are hardly any needs for ICT in the perfect world, costly information processing, communication, delays and errors can justify ICT investments. Therefore, the study extends the traditional transaction cost attribute of frequency with complexity [20, 21], timeliness and accuracy [13, 29]. They play the role of coordination cost attributes. Although timeliness and accuracy have been utilized to measure the IS success [11], in this study they set the requirements which can lead to the ICT investments. For further research, the study has contributed theoretical findings to be tested in the empirical studies. This applies especially to timeliness and accuracy. A theoretical challenge is to take into account a trade-off between delays and errors [3].

6 Conclusions

Based on an economic analysis of a theoretical model, the study proposes that frequency of the activity and timeliness and accuracy required in the activity increase the ICT investments when the expected net present value of the activities and ICT investments has excatly one viable maximum. Complexity of the activity has an ambiguous influence on these investments. The effect of frequency of the activity is supported by theoretical and empirical studies of transactional frequency [6, 30]. Frequency as a coordination cost attribute aggregates all kinds of coordination costs, both direct and indirect. Although the costs of information processing, communication, delays and errors per activity are low, ICT can yield large savings in coordination costs if the activity is very frequent. Contrary to theoretical and empirical studies of product complexity [6, 20], complexity of the activity can decrease the ICT investments. The costs of ICT in more complex activities can be so high that they exceed the savings in coordination costs.

In order to analyze timeliness and accuracy required in the activity, this study introduces the timeliness rate and the accuracy loss. When the timeliness rate is higher, the discounting of the benefits of the outcome results in higher costs of the delay and the ICT investments should be larger. Respectively, when the expected accuracy loss is higher, the reduction from the value of the activity causes higher costs of the error and the ICT investments should be larger. The effects of timeliness and accuracy seem to coincide with empirical findings [24].

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