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Accounting for cognitive time in activity-based costing: A technology for the management of digital economy

Natallia Pashkevich [a], Fabian von Schéele [b], Darek M. Haftor [b,c,*]

[a] Södertörn University, Stockholm, Sweden
[b] Uppsala University, Uppsala, Sweden
[c] University of Economics and Human Sciences of Warsaw, Poland

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ABSTRACT

Human cognitive time has become a key asset of the digital economy, yet we lack the means to manage it. In response to that need, we propose a technology to manage cognitive time in economic organizations. This technology is called *cognitive time-driven activity-based costing* (CTABC), and it extends the established time-driven activity-based costing technology. CTABC accounts for human agents' cognitive time and the fact that cognitive time typically does not equal physical clock time for a given economic activity. CTABC also unearths a hidden lever effect that leads to considerable economic inefficiencies. An illustration of the proposed CTABC shows the limitations of contemporary approaches to cost assessments, which ignore errors caused by workers' cognitive time estimation. This paper contributes to the literature on cost accounting technology and the future of the digital economy. Specifically, it enriches the literature on the problem of the accuracy of employees' time estimates.

1. Introduction

> "*In an information-rich world, the wealth of information means a dearth of something else: a scarcity of whatever it is that information consumes. What information consumes is rather obvious: it consumes the attention of its recipients. Hence a wealth of information creates a poverty of attention and a need to allocate that attention efficiently among the overabundance of information sources that might consume it.*"
>
> H.A. Simon (1971:40–41)

In today's competitive business environment, cost accounting systems must provide accurate information to managers so that they can make well-grounded decisions without negative impacts on the quality of products and services (Ganorkar et al., 2020; Hardan and Shatnawi, 2013; Zamrud and Abu, 2020). Without accurate cost accounting, managers cannot balance incomes and costs to sustain the endeavors of projects and govern organizations, firms, and even whole economies (Berisha, 2017; Ganorkar et al., 2020; Hardan and Shatnawi, 2013). Cost management is crucial for both for-profit and not-for-profit organizations that aim to be competitive and cost efficient (Hofmann and McSwain, 2013; Stouthuysen et al., 2014; Varila et al., 2007). Although the importance of cost accounting is beyond reasonable doubt, studies have shown that understanding cost structures and dynamics and cost assessments is not a trivial task for accountants and managers (Berisha, 2017; Hardan and Shatnawi, 2013; Uyar and Kuzey, 2016).

In recent decades, a number of cost accounting systems and approaches have been developed, including traditional costing systems, the activity-based costing (ABC) system, and the time-driven activity-based costing (TDABC) system (Barros and da Costa Ferreira, 2017). Whereas ABC was developed to address the limitations of traditional costing systems, TDABC was developed to overcome the fundamental limitations of ABC, including the complexity of the ABC system, high implementation and maintenance costs, and difficulties in collecting quantitative data on cost drivers through interviews (Siguenza-Guzman et al., 2013). Although some studies report that TDABC is useful for decision making, others indicate that TDABC's supposed advantages cannot be justified (Keel et al., 2017; Mortaji et al., 2013). Besides criticisms of TDABC in relation to the structural shortcomings of the basic theoretical assumptions and calculation procedures, the variety of time drivers and the lack of availability of reliable and accurate time estimates (Barros and da Costa Ferreira, 2017) also pose challenging research questions. These questions have become even more challenging for service firms that function in the new digital economy, where human time is central to cost assessment (Devece et al., 2017; Laudien and

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* Corresponding author at: Department of Informatics & Media, Uppsala University, Box 513, SE-75120 Uppsala, Sweden.
E-mail address: darek.haftor@im.uu.se (D.M. Haftor).

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Pesch, 2019).

Human experiences of durations and time are currently a popular area of study in various branches of the social sciences (Ogle, 2015). A recent example includes Hägglund's philosophy of life, where time is regarded as the key conditioner of human life. Under this view, time makes life worth living (Hägglund, 2012, 2019). In Rosa's theory of society, time is regarded as the defining feature of emerging social behavior, as articulated in the notions of "high-speed society" (Rosa, 2010) and "social accelerations" (Rosa, 2013). Other examples include various accounts of temporality in the study of social organizations (Orlikowski and Yates, 2002; Shipp and Jansen, 2021). In these accounts, objective time, measured by clocks and modeled on physical phenomenon, is juxtaposed with social time and cognitive time. This juxtaposition gives rise to tensions in organizational behaviors. A common denominator in the accounts of different kinds of time, particularly clock time versus cognitive time, is their opposition and incommensurability (Orlikowski and Yates, 2002). The implication is that we need to choose either clock time or cognitive time. This paper proposes a technology for cost accounting that transforms and overcomes such an opposition by relating clock time to cognitive time.

One major reason for the recent attention that time has received is the emergence of the digital economy (Barefoot et al., 2018; Brynjolfsson and Kahin, 2002; Carlsson, 2004). A defining feature of such an economy is that both consumers and organizations consume more and more services that are enabled by digital technology uses rather than acquiring tangible goods (Buera and Kaboski, 2012; Rubalcaba, 2007; Wölfl, 2005). In such an economy, marginal costs incurred by organizational operations tend to approach zero (Frew et al., 2016; Rifkin, 2014; Yang et al., 2019). It is typically only the first copy of software, songs, book texts, and movies that incurs costs. In contrast, producing subsequent copies of the original incurs nearly no costs. A second defining feature of the digital economy is the fact that the original service is provided by humans who use digital technologies (Mont, 2002), which makes *human time* the last key resource of economies. It is therefore imperative to understand the dynamics of human uses of time and their consequences for the costs and revenues of economic operations. This key issue is the focus of the present paper.

Although TDABC addresses the limitations of traditional cost accounting, ABC research also reports several challenges in the use of TDABC. For instance, scholars have emphasized the subjectivity involved in human agents' self-assessment and reporting of time of an activity. In TDABC, activities are regarded as central organizational mechanisms for cost generation. On the one hand, activities produce outputs (goods and services) that generate income, while on the other, activities require resources for their execution and thus generate costs associated with the use of each resource. The central idea in TDABC is that each activity uses the resources it needs for a certain amount of time. This feature of TDABC means that the assessment of time of resource use is central to the assessment of the cost of each activity. The recent development of the attention economy explains that human time constitutes a central asset—maybe the last asset of the digitally enabled economy—because human cognition has limitations in terms of the ability to assess durations and in terms of information processing (Davenport and Beck, 2000; Falkinger, 2007; Franck, 1999, 2002; Goldhaber, 1997; Simon, 1971).

The challenges of time assessment in the context of TDABC have been addressed in many studies emphasizing the subjectivity involved in human agents' time assessment and reporting (Barros and da Costa Ferreira, 2017; Cardinaels and Labro, 2008; Gervais et al., 2010; Mortaji et al., 2013; Siguenza-Guzman et al., 2013). For example, it was found that 30 % of errors in time estimation were due to imprecise evaluations of the time spent on certain tasks (Hoozée and Bruggeman, 2007). In another experimental study, an average overestimation bias of 35 % was found when participants provided time estimates (Cardinaels and Labro, 2008). It was also observed that time overestimation error could be as high as 50 % (Ratnatunga and Waldmann, 2010). Another study showed that self-reported duration of time can differ between −22 % to +38 % relative to the true duration (Barrero et al., 2009). All these self-time estimation errors can significantly magnify measurement error and affect the accuracy of the TDABC system. This situation is especially challenging in service organizations, where human labor is the dominant cost component, activities are conducted by human agents, and the human work time spent on these activities is typically reported by those human agents (Hardan and Shatnawi, 2013; Haroun, 2015; Tan and Netessine, 2014; Szychta, 2010).

The key assumption of TDABC is that the one kind of time it uses—clock time or physical time—is objective. The cognitive science literature, however, reports a significant difference between a worker's cognitive time and physical clock time (Block and Eisler, 1999; Levin and Zakay, 1989). This difference gives rise to cognitive time distortion (CTD), which is the relationship between perceived and physical clock time (i.e., the relationship between the duration of an event or activity as perceived by a human subject compared to the duration of such an event or activity when measured in clock time). This CTD has been shown to significantly affect key economic indicators such as profit, productivity, workload, and risk (von Schéele, 2001; von Schéele and Haftor, 2014, 2018; von Schéele et al., 2019, 2020). Because TDABC is strongly affected by subjectivity in the self-assessment of time, the aim of the study presented in this paper is to show how TDABC technology (a method or managerial procedure for assessing costs) can be improved by applying the theory of CTD to account for cognitive time distortion (Block and Eisler, 1999; Levin and Zakay, 1989). The assumption here is that such a technology may remedy the challenges of time assessment in traditional TDABC and thus support accurate and reliable decision making.

Our findings show that when considering both revenue and cost equations with their inherent CTD, the proposed technology can improve the accuracy of a firm's overall profitability. Thus, the proposed technology may become crucial for management in the digital economy, where human time is the last key resource. Our study also reveals that errors in time assessment without including CTD can result in inaccurate revenue and cost assessment and create a lever effect on profits. This lever effect can introduce error and mislead managers in their decision making based on their firm's profit.

The remainder of the paper is structured in the following way. First, a short review of different costing systems is presented, together with their key merits. Second, key underlying theoretical concepts are articulated, including the profit equation and CTD. The proposed technology is described, together with an illustrative case, including a demonstration of the effect of this technology on profitability. The paper ends with a discussion and the conclusions.

2. Key cost accounting systems

Over the years, a number of costing systems have been developed to capture detailed information on used resources and sources of inefficiency (Barros and da Costa Ferreira, 2017). The conventional costing system allocates direct and indirect costs to cost objects using cost drivers (Kaplan and Cooper, 1998). This system was appropriate when environments were stable with a small variety of activities and fixed overhead costs (Siguenza-Guzman et al., 2013). Traditionally, cost accounting overhead rates were arbitrary and were applied equally to all product costs. Therefore, this system led to inaccurate total product cost estimation (Tse and Gong, 2009) and created product cost distortion that affected pricing decisions (Gupta and Baxendale, 2008; Myers, 2010). The current business environment has changed radically since the emergence of new technologies, the shortening of product life cycles, and the increased variety of products and services. Overhead costs and their allocation have become more important than direct costs, particularly because several digital industries have operations with close to zero marginal costs (Rifkin, 2014). The weaknesses of the traditional cost system have become more problematic (Tse and Gong, 2009).

The ABC system emerged in the 1980s to address the limitations of the traditional cost accounting system (Cooper and Kaplan, 1998; Kaplan and Atkinson, 1989). This system was more accurate in allocating overhead costs to different activities than the traditional cost system (Allain and Laurin, 2018; Mortaji et al., 2013), building on the assumption that products differ in production complexity and that the consumption of activities also takes place in different proportions (Siguenza-Guzman et al., 2013). In ABC, resource costs are assigned to an activity based on a cost driver. Then, costs are allocated from the activity to the product based on the product's consumption of that activity (Ganorkar et al., 2018; Javid et al., 2016). The information required by the ABC system regarding the time spent by employees on several activities is usually collected through interviews, observations, and surveys (Kaplan and Anderson, 2004; Siguenza-Guzman et al., 2013). In general, the studies that have applied the ABC system can be classified in the following way (Hoozée and Bruggeman, 2007; Szychta, 2010): (i) studies that have focused on ABC design with implicit assumptions and mathematical models of ABC; (ii) case studies of ABC implementation; (iii) survey studies that have attempted to identify contextual factors that affect the adoption and influence of ABC; and (iv) studies that demonstrate applications of ABC in the service sector. ABC gave rise to many studies within the area of cost accounting. However, because of high implementation costs, employee irritation, and difficulties in implementation, many companies abandoned the use of the ABC system (Carli et al., 2014; Herath et al., 2010; Javid et al., 2016).

The main reasons for ABC failure include difficulties in collecting, storing, and processing data, high implementation and maintenance costs, difficulties in linking cost drivers to individual products, and difficulties in collecting quantitative information on cost drivers through interviews. In addition to these problems, the subjectivity of time estimation by employees has received special attention (Carli et al., 2014; Gosselin, 2006; Herath et al., 2010; Kaplan and Anderson, 2004, 2007; Siguenza-Guzman et al., 2013). The traditional costing system and the ABC system are recognized as not providing accurate information about the consumption of resources and activities (Gunasekaran et al., 2005). To overcome some of the limitations of the ABC system, such as complexity, implementation difficulties, and high time maintenance consumption, this costing system was superseded by the TDABC system (Kaplan and Anderson, 2004).

Unlike in the ABC system, in the TDABC system, time plays a different role in cost allocation to cost objects (Cidav et al., 2020; Hoozée and Bruggeman, 2010). Cost allocation in TDABC is conducted in two phases (Kaplan and Anderson, 2004, 2007): (i) the cost per time unit of supplying resource capacity to an activity is calculated by dividing the total cost of supplying resource capacity by the practical capacity (i.e., the amount of time employees work without idle time); and then (ii) the time units required to perform an activity are estimated. For each activity, costing time equations are calculated based on the required time to perform each activity (Yilmaz, 2008). In these time equations, it is possible to represent all possible combinations of activities. An estimate of the time units required to perform an activity is collected through interviews or direct observations of employees. TDABC has been successfully implemented in several sectors, including farming, healthcare, hospitality, logistics, and service operations (Bank and McIlrath, 2009; Dalci et al., 2010; Everaert et al., 2008; Gervais et al., 2010; Kaplan and Anderson, 2007; Pernot et al., 2007; Somapa et al., 2010, 2011; Varila et al., 2007; Yilmaz, 2008). However, the findings of several case studies reveal shortcomings related to basic theoretical assumptions and calculation procedures (Gervais et al., 2010; Mortaji et al., 2013; Siguenza-Guzman et al., 2013). In particular, subjective self-time estimation error is shown to magnify measurement error significantly and affect the accuracy of the TDABC system (Cardinaels and Labro, 2008; Gervais et al., 2010; Mortaji et al., 2013; Ratnatunga and Waldmann, 2010; Siguenza-Guzman et al., 2013). Hence, a work activity may have one duration when measured by a clock and another when measured according to the worker's subjective assessment. This distinction gives rise to CTD. This challenge of incorrect time assessment of activities in the context of TDABC assessment can be resolved by including CTD in the calculations of TDABC.

3. Toward a new technology for cost accounting

The following section presents a detailed theoretical and mathematical interpretation of the profit equation and TDABC modeling. This interpretation starts with the definition of profit for any service produced. Thereafter, the notion of CTD is introduced as a relationship between physical clock time and cognitive time for a given event. Finally, the CTD is examined, along with its lever effect on profit.

3.1. Time-dependent service organizations and TDABC

Firms seek to generate profit in order to survive (Hadar, 1971). Profit is denoted as π and is calculated as the difference between total revenues (TR) and total costs (TC), formally presented in Eq. (1).

$$\pi = \mathrm{TR} - \mathrm{TC} \tag{1}$$

Profit may be generated by two sources: time of resources to execute activities and materials consumed by activities (Varian, 2014). This idea is formalized in Eq. (2).

$$\mathrm{Profit} = (\mathrm{TR} - \mathrm{TC})_{\mathrm{time}} + (\mathrm{TR} - \mathrm{TC})_{\mathrm{material}} \tag{2}$$

Because a service consists of bought and billed time, a cost activity in service production is part of both costs and revenues simultaneously. Profitability in a firm depends on correct time assessments with regard to both costs and revenues. We focus on the $(\mathrm{TR} - \mathrm{TC})_{\mathrm{time}}$ part of the formula because human working time represents the key cost component in many service companies. Here, TR corresponds to total revenues related to time, whereas TC refers to total costs related to time. TR corresponds to sales orders, whereas TC corresponds to purchase orders. All orders are fixed orders (Everaert et al., 2008).

The main costs of a service firm are linked not to an object (to a good, such as a product or material) but to a service. Thus, there are two levels of TDABC. The first is TDABC related to the *employee contract* (as described by Everaert et al., 2008). The service, however, is delivered with errors related to the *customer contract* (sales contract). Fig. 1 follows the analysis suggested by Everaert et al. (2008) and illustrates the employee contract (cost contract). However, the technique corresponds to the sales contract as well, with the additional consideration that the time delivered to the customer is more expensive because of the gross margin. Thus, to ensure a stable profit margin, the TDABC system must consider the sales contract as well. The overall profitability of a firm also depends on whether the gross margin is enough to cover the cost to serve the customer, in addition to whether sales prices can recover product costs (Shapiro et al., 1987). The cost to serve the customer usually includes order-related costs, specific logistics, administrative costs, and selling expenses (Everaert et al., 2008).

3.2. Cognitive time distortion

Given the aforementioned importance of time in profitability and TDABC calculations combined with this study's aim of accounting for the role of cognitive time, this section elaborates on the theory of CTD and its consequences. Profitability and TDABC calculations rest on the assumption that physical clock time is the correct reference system of time. The theory of CTD, however, highlights the fact that humans have different kinds of temporal experiences, enabling a distinction between physical time (i.e., clock time) and cognitive time (Block and Eisler, 1999; Levin and Zakay, 1989; Nembhard and Uzumeri, 2000). Humans also experience temporal duration differently (von Schéele and Haftor, 2014, 2018). CTD, which is denoted as τ_i, is understood here as the ratio between *cognitive time* (t_c) and *physical clock time* (t_p), as formalized in

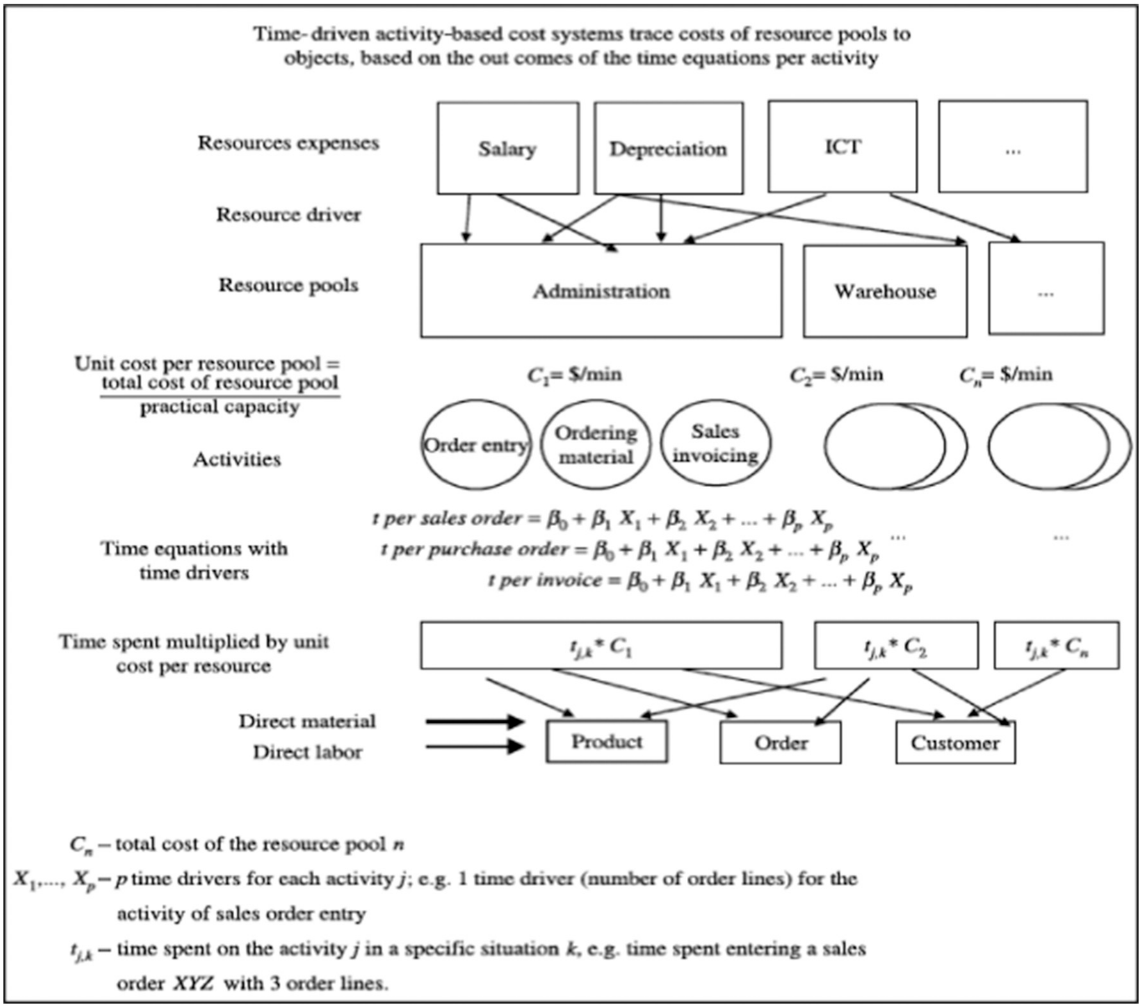

Fig. 1. Time-driven activity-based costing (Everaert et al., 2008).

the following equation:

$$\textit{Cognitive time distortion}: \tau_i = \left(t_c/t_p\right)_i \tag{3}$$

where *i* may be a process, project, event, activity, or service contract.

CTD in the assessment of 1 cognitive hour may vary between 1.08 and 2.14 physical hours (von Schéele et al., 2019). It has already been established that CTD significantly affects key economic indicators, including profit, productivity, workload, and risk (von Schéele, 2001; von Schéele and Haftor, 2014, 2018; von Schéele et al., 2019). However, the literature on cost assessment, particularly in relation to time, ignores the existence of CTD and its radical consequences, which are described in this paper.

3.3. CTD and its lever effect on profit

Mathematically, we need a distinct definition of any deviation of time spent on the sales contract and that spent on the cost contract. Therefore, we define CTD accordingly:

$$CTD_{sales} = \tau = \frac{t_s}{t_{0\ sale}} \tag{4}$$

$$CTD_{cost} = \delta = \frac{t_s}{t_{0\ cost}} \tag{5}$$

In Eq. (4), t_s refers to the *subjective* time assessment, referring to the time spent on work that is specified in the sales contract $t_{o\ sale}$. Thus, contract time serves as an objective point of reference for TR, indicating how large the distortion is with reference to the contracted sales time. Likewise, in Eq. (5), t_s signifies the subjective time assessment of time spent on work by an employee, which serves as a reference for the cost contract $t_{o\ cost}$. Thus, Eqs. (4) and (5) describe the CTD in distinct kinds of contracts: one generates TR (Eq. (4)), while the other generates TC (Eq. (5)). As demonstrated in Fig. 2, errors in time assessment create different modes of CTD with reference to TR and TC, resulting in a *lever effect* between TC (employee contract) and TR (sales contract; von Schéele et al., 2019; von Schéele and Haftor, 2018). This lever effect causes the TR per time unit to *decrease*, while the TC per time unit *increases* when the time volume is distorted. This CTD occurs *simultaneously* and influences both sales contracts and cost contracts. For instance, an employee underestimating the time spent on a certain work activity delivers more time to the customer than budgeted in the sales contract. Simultaneously, this worker becomes less efficient than budgeted in the cost contract. The changes in time volume create a lever effect on the profit. The influence of CTD on TDABC is also curvilinear (see Fig. 2).

As illustrated in Fig. 2, the budgeted profit (left) differs from the profit with CTD (right). The logic also applies to activities with shorter time durations. Therefore, the time spent on various activities (β) may seem to be the same in Eqs. (6), (7), and (8). However, the *error* in subjective time assessments (i.e., τ and δ) must correct the CTD of the sales order per time unit and the cost order per time unit to give a correct representation of the *profit per time unit*. Drury (2012) showed that all fixed contracts have a nonlinear variation between volume and value.

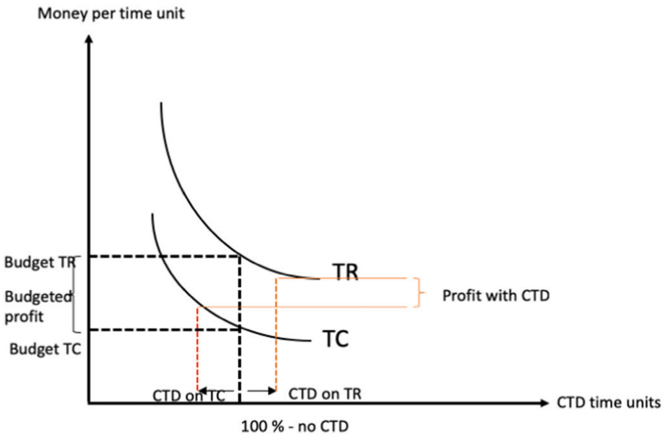

Fig. 2. Illustration of the curvilinear effect on the sales contract (TR) and cost contract (TC) and the lever effect on profit. The budgeted profit is displayed to the left of the figure, and the profit with CTD is displayed to the right. The dotted red lines mark the time distortion. At 100 %, there is no CTD at all in the sale contract or cost contract. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Thus, variations with respect to CTD will be multiplied by $\frac{1}{CTD}$, where the CTD may be time distortion from the sales contract or the cost contract.

4. Cognitive time-driven activity-based costing

This section presents key steps in the modeling of costs that account for human cognitive time. This approach is labeled here as cognitive time-driven activity-based costing (CTABC). This section starts with a detailed description of the key steps in TDABC adjusted to account for CTD. Thereafter, the time equations from TDABC are presented and remodeled to account for CTD. This process then enables calculation and comparison of profitability with and without the impact of CTD.

4.1. TDABC adjusted for CTD

The TDABC system considers only fixed-price contracts and has been shown to have a poor effect on profitability (Everaert et al., 2008). Accordingly, any deviation in time volume influences the sales contract and the purchase contract, and this influence is curvilinear (Drury, 2012). In the TDABC system, no assessment is controlled with reference to objective time, and there is no control of CTD. This omission of CTD is corrected for in the CTABC. Table 1 lists the steps suggested for TDABC to account for CTD.

In the development of CTABC, we follow the steps used in the description of the traditional TDABC. We first identify the various resource groups and total cost estimation of each resource group, which is assumed to be an objective measure of budgeted costs. We further assume that the practical capacity (time output) of each resource group and the unit cost of each resource group are *objective* measures that will serve as a reference point. When the time estimation for each event based on the time equation must be determined (Step 5), we include the CTD to correct time errors for each activity in the time equations. Finally, the last step where the unit cost of each resource group is multiplied by the time estimate for each event is adjusted to account for CTD.

Table 1
Key steps in CTABC (Source: based on Everaert et al., 2008).

Step	Description from traditional TDABC	CTD adjustment
1	Identify the various resource groups (departments).	This step remains the same.
2	Estimate the total cost of each resource group.	This measure is assumed to be objective—a budgeted cost for each resource group.
3	Estimate the practical capacity of each resource group (e.g., available working hours, excluding vacations, meetings, and training hours).	This estimate, which concerns the time output of each resource group, is assumed to be an objective measure—a budgeted time that will serve as a reference point for any deviation (i.e., CTD = 100 % of this capacity).
4	Calculate the unit cost of each resource group by dividing the total cost of the resource group by the practical capacity.	This step leads to a reference point—an objective unit cost—that is an objective cost/hour for each resource group.
5	Determine the time estimation for each event based on the time equation for the activity and the characteristics of the event.	In this step, CTD deviates from the true time elapsed for each activity. Therefore, each activity is reported with a time error in the time equations corresponding to CTD (see Eqs. (4) and (5)).
6	Multiply the unit cost of each resource group by the time estimate for the event.	This calculation is adjusted to account for CTD.

4.2. Time equations in TDABC

In modeling CTD in the assessment of β (beta) in time equations, we start with the time equations from TDABC (Everaert et al., 2008) and successively modify these equations with respect to Fig. 1. Accordingly, we include both the sales contract and the cost contract and model the profit of a service organization. Because of the lever effect, we distinguish between CTD in the sales contract (customer contract) and CTD in the cost contract (employee contract), as specified in Eqs. (4) and (5). The time equations in TDABC are presented from Everaert et al. (2008):

$$t\ per\ \underline{sales}\ order = \beta_0 + \beta_1\, X_1 + \beta_2\, X_2 + \dots + \beta_p\, X_p \tag{6}$$

$$t\ per\ \underline{cost}\ order = \beta_0 + \beta_1\, X_1 + \beta_2\, X_2 + \dots + \beta_p\, X_p \tag{7}$$

$$t\ per\ invoice = \beta_0 + \beta_1\, X_1 + \beta_2\, X_2 + \dots + \beta_p\, X_p \tag{8}$$

Eqs. (6), (7), and (8) are *similar* in Everaert et al. (2008). However, it is important to distinguish between these equations because miscalculation of the time spent affects the outcome of the analysis differently depending on whether it is a sales contract or a cost contract. Thus, total profit of a specified customer contract should be expressed as follows (see Eq. (2)):

$$\text{Profit}_{\text{TDABC}} = (\text{TR} - \text{TC})_{\text{time}} = X_j {*} t_{j,k} {*} C_{sale\ j} - X_j {*} t_{j,k} {*} C_{cost\ j}, \tag{9}$$

where

$t_{j,k}\ {*}\ C_1$ = time spent multiplied by unit cost per resource,
$C_{sale\ j}$ = total revenue of the customer contract with j specified activities,
$C_{cost\ j}$ = total cost of the resource pool n referring to j specified activities in a customer contract,
$X_j \dots X_p$ = p time drivers for each activity j; e.g., 1 time driver (number of order lines) for the activity of sales order entry.

In the following analysis, we compare Eq. (8) when corrected for CTD.

4.3. Time equations in TDABC accounting for CTD

Now, combining Eqs. (4) and (5) with Eqs. (6), (7), and (8), we obtain the corrected time per sales order and time unit (as well as time per purchase order). Note that in Eqs. (10) and (11), the CTD = τ indicates the error per time unit in reference to the customer contract and CTD = δ indicates the error of time assessment with respect to the employee contract, while:

$$t\ per\ \underline{sales}\ order\ \left(\underline{customer}\ contract\right) = \left(\frac{\beta}{\tau}\right)_0 + \left(\frac{\beta^*X}{\tau}\right)_1 + \left(\frac{\beta^*X}{\tau}\right)_2 + \ldots + \left(\frac{\beta^*X}{\tau}\right)_p \quad (10)$$

$$t\ per\ \underline{cost}\ order\ \left(\underline{employee}\ contract\right) = \left(\frac{\beta}{\delta}\right)_0 + \left(\frac{\beta^*X}{\delta}\right)_1 + \left(\frac{\beta^*X}{\delta}\right)_2 + \ldots + \left(\frac{\beta^*X}{\delta}\right)_p \quad (11)$$

$t_{j,k}$ (τ, δ) * C_1 = time spent distorted by CTD multiplied by unit cost per resource,
$C_{sale\ j}$ = total revenue of customer order including j specified activities,
$C_{cost\ j}$ = total cost of resource pool n referring to j specified activities,
$X_1 \ldots X_p$ = p time drivers for each activity j; e.g., 1 time driver (number of order lines) for the activity of sales order entry.

Note that the term $t_{j,k}$ (τ, δ) * C_1 is the time spent per unit cost *and per time unit*. According to these definitions, total profit per customer order can be expressed as follows (applying Eq. (2)):

$$\text{Profit}_{\text{CTABC}} = (\text{TR} - \text{TC})_{\text{time}} = X_j{}^*t_{j,k}\ (\tau,\delta)^*C_{sale\ j} - X_j{}^*t_{j,k}\ (\tau,\delta)^*C_{purchase\ j} \quad (12)$$

If Eq. (9) is compared with Eq. (12), we see that it is the length of time spent on each activity that has been changed. Thus, $t_{j,k}$ in Eq. (9) (indicating no time distortion) is changed in Eq. (12) to $t_{j,k}$ (τ, δ), stressing the time distortion in both costs and revenues, as indicated in Eqs. (4) and (5).

5. Comparing profitability of an order at the customer level: an illustrative example

After adjusting TDABC to account for CTD, the following question arises: How much does CTABC improve profitability in service operations? We compare the profitability per customer when TDABC includes CTD with the profitability when CTD is not considered.

We assume that the time drivers, X_i, for a certain customer correspond to $I = 2$, 3, and 4. Therefore, the time drivers are X_2, X_3, and X_4, while the duration of each activity is β_2, β_3, and β_4 time units. We now assume:

$C_{sale\ j}$ = 5 monetary units (MUs)
$C_{purchase\ j}$ = 3 MUs
β_2 = 2 time units (TUs)
β_3 = 3 TUs
β_4 = 4 TUs
$X_2 = 1$
$X_3 = 1$
$X_4 = 1$
τ = 1.1 (average time distortion of activities compared to *customer* contract).
δ = 0.9 (average time distortion of activities compared to *employee* contract).

First, we start with Eq. (9):

$$\text{Profit}_{\text{TDABC}} = 5^*(2+3+4) - 3^*(2+3+4) = 5^*9 - 3^*9 = 18$$

Now, we study the distortion of the profit in Eq. (12):

$$\text{Profit}_{\text{CTABC}} = 5\left(\frac{2}{1.1}+\frac{3}{1.1}+\frac{4}{1.1}\right) - 3\left(\frac{2}{0.9}+\frac{3}{0.9}+\frac{4}{0.9}\right) \approx 5^*8 - 3^*10 = 40 - 30 = 10$$

Thus, the relative change in profitability of the activities in the customer contract is:

$$\frac{\text{Profit}_{\text{CTABC}}}{\text{Profit}_{\text{TDABC}}} = {}^{10}\!/_{18} \approx 0.56$$

As illustrated in the comparison of the two profits calculated earlier, the profit correcting for CTD is 44 % smaller than the profit assuming that there is no CTD at all in the service delivery process. Because of the *lever effect* (see Fig. 2), even if TDABC gives better information about the profitability of a certain contract, it still misses the errors caused by CTD. As illustrated in this example, these errors rapidly increase the lever effect. If the profit defined in Eq. (2) largely depends on time, it is suggested here that CTD must be considered. Otherwise, the errors in the final calculation will be large (Table 2).

Table 2 shows the dynamics of the lever effect when CTD is included in the TDABC system. The right-hand column shows the ratio $\text{Profit}_{\text{CTABC}}/\text{Profit}_{\text{TDABC}}$. This ratio reflects the actual economic loss generated at a given level of CTD. Because CTD is accounted for in both the revenue and costs contracts, as these two interact, a nonlinear effect emerges even at a low level of CTD. These figures show the need for managers to account for the distinction between physical clock time and employee perceptions of activity duration.

6. Discussion and conclusions

In today's highly competitive environment, there is an urgent need to calculate costs and revenues accurately so that companies can survive and ensure long-term profitability (Berisha, 2017; Ganorkar et al., 2020). Calculating the cost of products and services, however, remains a difficult exercise to ensure that costs do not exceed market prices. The TDABC model was proposed to remove the limitations of traditional costing systems and the ABC model. The distinctive feature of TDABC is that the time of an activity is at the forefront of the assessment of the cost of that activity. However, employees' time estimates are prone to measurement errors in cost assessment (Barros and da Costa Ferreira, 2017; Cardinaels and Labro, 2008; Gervais et al., 2010). They lead to misinformed managerial decision making because TDABC accounts for only one kind of time, namely physical or clock-time, assuming that it is objective. The cognitive science literature shows a significant difference between a worker's cognitive time and physical clock time, understood as the relationship between perceived time and physical time (Block and Eisler, 1999; Levin and Zakay, 1989). In this paper, we propose an updated version of TDABC that accounts for human agents' cognitive time and the fact that cognitive time typically does not equal physical time, hence producing CTD. The CTABC technology proposed in this paper remedies the shortcomings of time assessment using traditional TDABC by accounting for CTD and incorporating it into the TDABC calculations.

The present study contributes to cost accounting research on the problem of time subjectivity in employees' self-assessments of activity duration. It does so using a novel factor that alters the assessment of costs in TDABC. This factor is a worker's cognitive time. In this study, we

Table 2
Correspondence between the assumed profit based on TDABC and CTABC technologies.

CTD level	$\text{Profit}_{\text{TDABC}}$	$\text{Profit}_{\text{CTABC}}$	Ratio: $\text{Profit}_{\text{CTABC}}/\text{Profit}_{\text{TDABC}}$
1.00	18	18	1.00
1.05	18	14	0.77
1.10	18	10	0.56
1.15	18	7	0.38
1.20	18	3	0.16
1.25	18	0	0
1.30	18	−4	−0.22
1.35	18	−8	−0.44
1.40	18	−13	−0.72

advocate the use of the CTABC model to remedy the challenges of time assessment in traditional TDABC. In particular, we show that when CTD is included in both revenue and cost equations, it is possible to control overall profitability with CTABC. While traditional TDABC presents a more positive picture of the profitability of a certain contract, it omits errors caused by CTD. These errors are due to a lever effect and can quickly become large, significantly affecting final calculations.

The CTABC technology proposed in this paper accounts for time loss on both the revenue and cost sides of economic operations. The interaction between the two losses generates a lever effect that leads to a strong nonlinear impact on the profit of economic operations. Even a minor level of CTD generates large economic inefficiencies, as illustrated here. The proposed CTABC system accounts for, articulates, and thus controls and mitigates such inefficiencies due to the inadequate use of human time. This system is particularly important given that societies are steadily advancing into the digital economy (Brynjolfsson and Kahin, 2002), where human time is the last key resource of economic operations. For example, the U.S. IT giant IBM employees nearly 300,000 staff members. Many sell their time to clients in exchange for their services. Over a year, the economic impact if IBM's managers could reduce time leakage by only 1 % could be huge.

The theoretical significance of this contribution lies in the fact that the literature on cost accounting, specifically ABC and TDABC, focuses on human agents' physical time assessment. The CTABC system proposed here simultaneously accounts for a dual temporal experience, accounting for both cognitive and physical time. The relationship between cognitive and physical time gives rise to CTD, which affects the profitability of activities. The novel profit equation presented in this paper shows how CTD affects the profitability of activities in customer contracts.

For practitioners, our study shows that the profitability of activities can be managed by controlling CTD in TDABC. This finding highlights the need for further research on how to control, measure, and govern workers' cognitive time. It suggests that managers should inform and train employees in their perception of working time and its relation to physical time. Further research is also needed to inform managers on how to control CTD and what type of feedback is required to manage and improve CTD assessment. Further research could examine the implementation of CTABC and show how the impact of cost calculations accounting for CTD could affect the profitability of a firm.

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- This research has not received funding from any organization, private or public body.
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Data availability

No data was used for the research described in the article.

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Natallia Pashkevich is an assistant professor of accounting at Södertörn University in Sweden. Her research focus is the productivity of information and knowledge workers, including the productivity effects from the sue of digital technologies.

Fabian von Schéele is an associate professor emeritus, currently serving part time at Uppsala University, Sweden. He directs a research program on the economic implications of cognitive time.

Darek M. Haftor is professor of Information Systems at Uppsala University, Sweden. He leads a research program on the economic value creation from the use of digital technologies, including productivity and novel digital business models. He is the contact author for this submission, at: darek.haftor@im.uu.se.