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Wake up or Fall Asleep: Value Implication of Trusted Computing

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Wake up or fall asleep-value implication of trusted computing

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Abstract More than 10 years have passed since trusted computing (TC) technology was introduced to the market; however, there is still no consensus about its value. The increasing importance of user and enterprise security and the security promised by TC, coupled with the increasing tension between the proponents and the opponents of TC, make it timely to investigate the value relevance of TC in terms of both capital market and accounting performance. Based on both price and volume studies, we found that news releases related to the adoption of the TC technology had no information content. All investors, regardless of whether they are individual investors or institutional investors, or they are wealthy individual investors or less wealthy individual investor, all have similar views on the value of TC. Further, we show that the accounting benefit gained from the adoption of TC is trivial, which might explain the price invariance and volume invariance we observed in the stock market.

Keywords Trust computing · Trading volume · Trading price · Information contents · Different types of investors · Firm performance

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1 Introduction

1.1 Crossfire

Almost 10 years have passed since *trusted computing (TC)* technology was introduced to the market; however, there is still no consensus on its value. Since day one, TC technology has attracted intensive crossfire. The TC proponents such as International Data Corporation [1], the Enterprise Strategy Group [2], and Endpoint Technologies Associates claim that this technology will allow computers to provide hardware-based security that cannot be bypassed by most software attacks [3]. Until now, around 200 members including AMD, Intel, Microsoft, Sun, IBM, and Dell have joined the Trusted Computing Group (TCG, formerly TCPA). Since 2004, most major chip, computer, and network manufacturers have shipped TC-enabled systems (servers, desktops, laptops, tablets, motherboards, and chipsets) in accordance with the TCG specifications [4]. Numerous applications have been developed to support TC technology. Some examples are Microsoft's BitLocker Drive Encryption, Linux's Enforcer, Seagate's Full Disk Encryption, TCG's Trusted Software Stack TrouSerS, Java interface to TPM capabilities TPM/J, and TPM-supported Grub bootloader Trusted Grub. As the number of manufacturers supporting TC increases, the US Army and the Department of Defense require that every new small PC purchased since 2007 be equipped with TC hardware [5, 6]. The International Data Corporation predicts that almost all portable PCs and most desktops will include TPM chips by 2010. The diffusion of TC technology may lead to "the biggest change of the information landscape since decades" [7].

On the other hand, the TC opponents such as the Electronic Frontier Foundation, the Free Software Foundation, GNU/Linux and FreeBSD communities, the software development community, and many security researchers claim that the technology exposes end-users to new risks of anti-consumer and anti-competitive behavior. The root of this problem is that the technology puts trust in the creators of TC systems instead of the owners of the platforms. Ross Anderson [8] pointed out that the remote censorship feature of TC technology may be misused by those who design systems and software. As a result, the users who own the platforms may lose control over the digital objects they created. Another consequence of using TC technology is that software suppliers can make it very difficult and costly for software users to switch to their competitors' products. It also raises privacy concerns since each trusted platform module has a unique key-pair that identifies the platform (the privacy concerns can be mitigated using the direct anonymous attestation in TPM version 1.2). It has been argued that TC technology will provide only minor protection against worms and viruses. Due to these concerns, opponents recommend against the adoption of TC technology until the owner control, competition, interoperability, and other similar problems are addressed.

Trusted computing could be used for good purposes as well as for bad purposes [8–10]. To understand this extremely controversial issue, we briefly summarize the key concepts and prospective positives and negatives. Regardless of whether one supports TCG, he/she should care about how individual customers perceive TC technology because it is the end users' perception that really determines the future of TC. Given the long-lasting, on going, and increasingly intensive tension over the value of TC between academic researchers and individual vendors, we believe that it is important and timely to understand (1) whether consumers really understand the value of TC; (2) who understands the value of TC, sophisticated institutional investors or small individual investors, wealthy investors or less wealthy investors; and (3) does adoption of TC really lead to an overall better firm financial performance? Going through this exercise will enable us to answer the question between the two sides of TC technology, which side is winning the battle and who might ultimately win the battle.

1.2 Key concepts

There are five key technology concepts in TC: endorsement key, secure I/O, memory curtaining, sealed storage, and remote attestation. First, the endorsement key is a 2,048-bit RSA key pair created randomly on a security chip at manufacture time. The endorsement key cannot be changed after it is created. The private key never leaves the chip; it is used to generate a digital signature on a random number to prove the identity of the security chip in a secure transaction. The public key can be used for attestation and encryption of sensitive data sent to the chip. Second, the secure I/O protects data traveling between a user and a software process. It uses check sums to verify that the software involved in I/O process is not compromised. Third, the memory curtaining provides full isolation of sensitive areas of memory for protected execution of software processes. Next, the sealed storage encrypts private information so that it can be decrypted only in certain platform configurations (software and hardware combination). Finally, the remote attestation allows a remote party to verify the security status of the software running on a local computer based on a certificate generated by the trusted hardware at the local computer.

1.3 What are the positives?

Trusted computing technology, if implemented appropriately, can be used to protect computer systems for their owners. For example, the TC technology could be used to thwart identity theft in online banking transactions. When a customer is connected to a bank's server, the remote attestation could be used to check the security status of the software running on the customer's platform and the server's. Then, the customer would browse the page if the server could produce the correct certificate before the customer sends his/her account number and PIN to the bank over a secure channel. The sealed storage function could be used to assure computer users that no spyware is able to steal the users' sensitive information such as biometric authentication data. The remote attestation, secure I/O, and memory curtaining could be used to prevent cheating in online games by verifying that all players connected to the server are running unmodified copies of software.

1.4 What are the negatives?

TC technology can be potentially misused by its creators to secure computers against their owners. In digital rights management (DRM), for example, a company who sells digital products such as music and movies could use remote attestation to send their files to only the legitimate players that enforces their DRM rules. The sealed storage would prevent users from opening the files with tampered players or other players. The memory curtaining and the secure I/O could be used to prevent users from making unrestricted copies when the files are playing. With TC technology, the users' computers could be potentially controlled by governments, software vendors, and digital content providers in a way that restricts the users' freedom of choice. After all, the computer owners do not have access to the private keys stored in the security chips in their computers.

1.5 Who wins?

There is no settled conclusion about who wins the fight on TC. Open debates on TC technology have been going for nearly 10 years. It is timely to investigate the current status and future trend of this technology in the global market in an objective and scientific manner.

For this purpose, we investigate how the capital market responds to news releases related to major corporations adopting TC technology, such as the release of TC hardware and software, joining the TCG, or confirming the support of TCG. Much to our surprise we found that there was no abnormal price response to the adoption of TC technology in practice, failing to support the claims that the announcements of such events have information content. Furthermore, different investors, regardless of whether they are sophisticated institutional investors or less sophisticated individual investors, do not value TC technology. This finding is very confounding because TC technology has demonstrated its potential to bring in "the biggest change of information landscape since decades," and the stock market is supposed to respond to any information that can change investors' beliefs about a firm's future profitability. However, the capital market seems to have totally ignored the adoption events as if those events had never happened. So, why does not the efficient capital market reflect this information? Is it because the market has not sensed a winner in the fight between proponents and opponents of the technology?

To investigate whether the capital market really behaves rationally, we turn to studying the impact of TC on accounting performance. We investigate whether the adoption of TC technology leads to a better future performance. Our portfolio and multivariate regression analyses also show that the adoption of TCG has no impact on the actual accounting performance as well. This means that the lack of impact on the capital market on TC can be explained by the fact that the adoption of TC cannot lead to a company's better future financial performance. Since the adoption of TC does not change investors' expectation of a firm's future profitability, there is no price or volume response to the announcement of TC adoption.

Looking ahead, it remains unclear whether the technology will gain popularity among computer users, as they have not decided "whether they really trust the good guys (governments and software vendors) more than they fear the bad guys (hackers)" [11]. Ultimately, it is computer users instead of vendors who decide the fate of TC. The users need to weigh their benefits against the costs of enabling the technology [9]. It does not appear that users believe that they will benefit significantly from the technology at this moment because protection against worms and viruses is limited [12], and some of the features provided by TC can already be established by today's smart card supported systems. On the other hand, users' costs could be high due to the interoperability, competition, owner control, and similar problems inherent in the TC technology. Even if the vendors have the power to populate the market with TC-enabled products, users have the option of not enabling the TC functionality if choices were given. Just as Sony and Apple announced their DRM-free music after the Sony BMG copy protection scandal, the vendors of TC may face the same situation if the opposition is too vocal. To really make TC work, the proponents of the technology need to address users' concerns about the technology, while at the same time providing more incentives or benefits for users to turn on TC functionality. This demands more research on both the technical side and the economic side of TC. Before that really happens, we expect the capital market to remain impervious to the news announcements related to the adoption of TC.

1.6 Outline

The rest of this paper is organized as follows. Section 2 reviews the related work, Sect. 3 develops our hypotheses, and Sect. 4 describes our research methodology and data collection criteria. Section 5 presents our empirical results, while Sect. 6 discusses the paper's contributions and implications for theory and practice.

2 Related work

The trusted computing group (TCG) [7] defines a set of TC specifications [13–15] aiming to provide a hardware-based root of trust and a set of mechanisms to propagate trust to applications as well as across platforms. The root of trust in TCG is a tamper-resistant hardware engine, called Trusted Platform Module (TPM). TPM is assumed robust against both hardware and software attacks from either the underlying host or external sources. It is a self-contained coprocessor with specialized functions such as random number generation, RSA key generation, RSA public key algorithms, SHA-1 hash function, HMAC function, and volatile and non-volatile memory. TPM is associated with an attestation identity key (AIK) pair. The AIK is issued by the Privacy Certification Authority (P-CA), together with a certificate that binds the public AIK to TPM. The private AIK can be used only by TPM to generate signatures. TPM is also installed with a unique endorsement key (EK) pair by the manufacturer before shipping, which is used exclusively for data encryption purposes. The private EK is securely held in TPM for decryption operations, and the public EK is associated with an endorsement credential and accessible to any application for encrypting data to TPM. TPM facilitates storage of integrity measurement metrics of the underlying platform to the internal registers, and reporting of the metrics. In particular, TPM contains a set of platform configuration registers (PCRs), which are used to record the integrity and configuration metrics of a running platform from booting to OS loading to application software loading. Each PCR value is the SHA-1 hash value of its current value concatenated with the new measured value of the protected objects, (i.e., PCR[n] ← SHA1(PCR[n] || latest measured value). Measurement of a platform's integrity results in the generation of measurement events, which comprises two classes of data: measured values, which are representations of the data or program code to be measured; and measurement digests, which are hashes of the measured values. The measurement digests are stored to PCRs in TPM, while the measured values are stored to the stored measurement log (SML) outside TPM. With integrity measurement in place, TPM (attestator) can attest to a remote challenging platform (challenger) the integrity state of its underlying platform through platform attestation. In particular, attestation works as follows: the challenger sends a challenge message to the attestator, who then returns the related PCR values signed by its attestation identity key (AIK), together with the relevant SML entries and the corresponding credentials. The challenger validates the response, and decides whether the attestator platform is trusted for its intended purpose.

TPM provides hardware-based secure storage for sensitive data by storing a storage root key (SRK) inside the chip and never exposing it outside. Sealed storage is an essential security mechanism offered by TPM. Sealed storage protects sensitive data with integrity values. In particular, besides applying an encryption key (RSA public key encryption) to encrypt the data, one or more PCR values are stored together with protected data during the encryption. Consequently, TPM releases protected data only if the current PCR values match those stored during encryption. The encryption key is protected either directly by SRK, or by a key protected by the SRK. Hence, the SRK acts as the root of trust for storage, and all encryption keys can actually form a key hierarchy. SRK is the only storage key permanently residing within TPM.

The designs and applications of TC have been rigorously studied in recent years [16, 17]. An incomplete list of the designs and applications include digital rights management [18, 19], access control enforcement [20–22], inference control [12], privacy protection [23–25], remote attestation services [26–28], secure auction [29], e-voting [30], online gaming [31], grid computing [32], and integrity measurement [33]. While these studies demonstrate that TC technology can be used for many good purposes, it is not clear whether these benefits will outweigh the concerns that the users are not trusted from the root.

To the best of our knowledge, our research is the first attempt to investigate the users' acceptance of TC from a capital market prospective. We investigate whether adoption of TC technology is associated with increased trading price and trading volume, indicating that consumers appreciate the value of TC technology. We study whether different investors (institutional investors vs. individual investors, wealthy vs. less wealthy individual investors) have different valuations of TC technology. We also investigate whether such an adoption will lead to improved future accounting performance, indicating that TC technology do change the bottom line.

3 Information release and market response

According to prior event studies [34], information measures the variation in expectations about the outcome of an event (e.g. the release of annual or quarterly earnings, news releases regarding the appointment of a new CEO, analysts' forecasts, etc). Information released by a firm is regarded as rich in information content if it has impact on the stock price of that firm. An underlying assumption for event studies is market efficiency, which suggests that stock prices incorporate all available value-relevant information about the value-creation and growth prospects of a firm. Stock price has a forward-looking nature and takes into account expected future firm performance; hence, stock price fundamentally reflects investors' expectation of a firm's future profitability. If one information release includes information that fundamentally changes that expectation, then the announcement of such information should be associated with an abnormal stock price.

In the valuation literature, researchers have used event study to document the price and trading volume response to IT investments, such as innovative IT investments [35] or IT infrastructure investment [36]. By studying the market response to the announcements of ERP implementation [37], researchers found that there were significant abnormal stock market returns for ERP vendors such as PeopleSoft and SAP. Using an event study methodology, Ettredge and Richardson [38] measured the reactions of investors to hacking or denial-of-service events for B2B Internet firms and B2C Internet firms.

As the pros and cons of TC technology are ardently discussed, all these characteristics also could be captured, digested, and understood by investors in the stock market as well. Following previous valuation studies [35–38], in this study we adopt event study methodology to investigate the value relevance of TC technology. If capital market participants perceive the value creation of TC technology, then new information related to TC adoption should increase investors' expectations about a firm's future profitability, resulting in an increased stock price. However, if investors do not understand the value of TC adoption and do not believe that TC will change a firm's future profitability, then the TC announcements will have no information content. In such a case, there will be no price response to the announcements of TC.

H1 If TC technology adoption is perceived to be good (bad) news, then the announcements of TC technology related adoption should be associated with an increased (decreased) stock price.

Volume response is different from price response. Price measures the "average" investor's response, while volume reflects an individual's asymmetric perceptions of a firm's future prospects [39]. Even though price and volume are often positively correlated, they represent two different aspects of an individual's expectation adjustment processes [39]. The impact of newly released information on investors might vary because (a) investors have different capabilities in terms of information acquisition (they might use different information for evaluation purposes), and (b) even if they use the same sets of information to make purchase decisions, their interpretation of the same information might differ as well. Thus trading volume arises when there is a lack of consensus regarding newly released information among investors. However, if none of the investors values TC technology, or they interpret a TC announcement homogeneously, compared to a non-event period, there will be no more volume occurring within the event period. Therefore no matter whether TC technology adoption is considered as favorable or unfavorable by capital market participants, as long as investors value TC and have different interpretations of the TC-related announcements, then we expect

H2 TC technology related announcements are associated with increased over-all trading volume.

An increase in the trading volume might not mean that all investor groups understand the value of the information. As suggested by previous literature [40], due to the intrinsic information access and digest capabilities difference as well as resource owned, when making investment decisions, big investors tend to rely more on interim disclosure information due to their high information acquisition skill as well as the rich resources they owned. Small investors tend to place great emphasis on the public disclosure information (i.e., the annual report), and are more likely to trade on pro forma information [41]. Due to the sophisticated nature of TC technology, the announcement of the adoption of such technologies might be appreciated only by certain groups of investors, such as institutional investors or wealth individual investors, who have the resources and capability to acquire and digest TC related information. Given the complexity nature of TC technology, we expect that

H3 Different investors respond differently to TC technology related announcements. Institutional investors increase their trading relative to individual investors when facing TC announcements, and among individual investors, wealthy investors, as opposed to less wealthy investors, trade more in response to TC announcements.

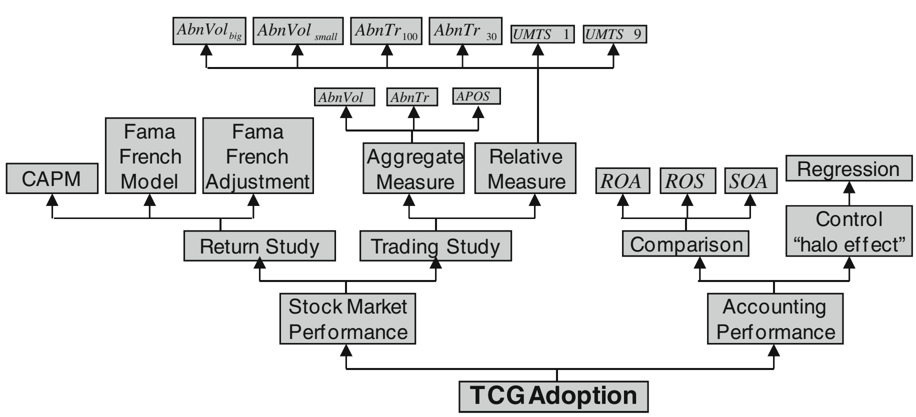
4 Research methodology

4.1 Methodology development

Figure 1 provides an overview of the key conceptual constructs that we adopt to study the market response and performance impact of TC technology related adoption. Both accounting and capital market performance are used because it has been observed that relations between performance and technological investment may be difficult to detect using contemporaneous accounting-based output measures. Accounting tracks short-term performance whereas benefits from technological investments may be realized over a longer time frame [42].

For the capital market perspective, we adopt event study methodology to study both the return (measures the overall market perception) and the trading response (measures the consensus among investors) to the announcements of

Fig. 1 Basic research model



TC. For the trading perspective, in order to capture the possibility that TC might be understood only by certain groups of investors (e.g., wealthy individual investors or institutional investors), we study both aggregate as well as relative trading behavior. For the accounting perspective, we study the future performance impact of TC adoption while controlling for the historical financial performance (Halo Effect).

Event studies, also called short window studies, have been widely used in the accounting and finance literature to study whether the market responds to events, such as IT investments, newly created CEO, CIO, outsourcing, ERP, etc. Because stock prices incorporate all relevant available information about the value-creation and growth prospects of a firm, they may be used to measure the expected influence of technological investments on long-term performance. If the announcements of TC technology related adoptions have information content, then an abnormal stock price and trading volume should be observed around such events.

4.1.1 Price response

In order to calculate the abnormal return of one event, we need to calculate the expected "normal" stock return. Any stock return above the normal stock return is called abnormal stock return. For robust checking purposes, three asset pricing models, Asset pricing model (CAPM) model, Fama–French three-factor model, and Fama–French adjusted model, were used to control factors that are known to influence stock returns. We elaborate each of them below.

4.1.1.1 Asset pricing model The CAPM states that the expected return of a security equals the rate on a risk-free security plus a risk premium. Following previous research [36], a *255-day sample period*, which begins 300 days before the event day (i.e., $t - 300$) and ends 45 days before the event day (i.e., $t - 45$) is used to estimate the risk measure (beta):

$$R_{it} = \alpha_i + \beta_i R_{mt} + \varepsilon_{it} \tag{1}$$

where R_{it}: daily stock return of firm i on day t, R_{mt}: market rate of return using the equally-weighted portfolio on day t, β_i: systematic risk of the firm i and α_i is an intercept, ε_{it}: error term.

Then, based on the estimated α_i and β_i, we estimate the expected "normal" firm returns. The prediction error or the abnormal return for firm i at day t is computed as:

$$\mathrm{AbnR}_{it} = R_{it} - (\hat{\alpha}_i + \hat{\beta}_i R_{mt}) \tag{2}$$

A 5-day event window, beginning 2 days before the event day (i.e., $t - 2$) and ending 2 days after the event day (i.e., $t + 2$) was used to analyze the price reaction to TC technology related announcements. The days from $t - 2$ to $t - 1$ are included because there might be information leakage before firms officially announce their TC technology adoption to the market; while the days from $t + 2$ to $t + 1$ are included because the market might not respond to TC technology announcements immediately. However, we expect that the most significant market reactions, if there are any, happen on day 0.

4.1.1.2 Fama and French three factor model In their research [43] the authors extend the CAPM model with two more factors, small cap and book-to-market ratio, because stocks with small cap and a high book-to-market ratio are associated with higher return. Thus, our second estimation method employs the Fama–French three-factor model to calculate the abnormal returns as follows:

$$R_{it} = \alpha_i + \beta_{i1} R_{mt} + \beta_{i2}\,\mathrm{SMB} + \beta_{i3}\,\mathrm{HML} + \varepsilon_{it} \tag{3}$$

where R_{it}: the rate of stock return of the ith firm on day t, R_{mt}: the market rate of return using the equally-weighted portfolio on day t, Small Minus Big (SMB): the average return on the three small portfolios minus the average return on the three big portfolios, High Minus Low (HML): the average return on the two value portfolios minus the average return on the two growth portfolios,[1] ε_{it}: error term.

We estimated parameters (α_i, β_{i1}, β_{i2} and β_{i3}) in Eq. 3 from stock market data using the 255-day sample period. And the final abnormal return of firm i on day t is:

$$\mathrm{Abn}R_{it} = R_{it} - \left(\hat{\alpha}_i + \hat{\beta}_{i1} R_{mt} + \hat{\beta}_{i2}\mathrm{SMB} + \hat{\beta}_{i3}\mathrm{HML}\right) \tag{4}$$

Again the daily as well as aggregate abnormal return in the time window ($t - 2$, $t + 2$) is calculated to capture the information leakage and delayed effect of an event.

4.1.1.3 Fama French adjustment method For this method, we identify the peer group of each firm based on its size and market-to-book ratio. Then the abnormal returns of each event is calculated by subtracting returns of market portfolios composed of peers with similar market-to-book ratios and size from the actual returns earned on each firm event. We title this method as Fama French Adjustment.

4.1.2 Aggregate trading response

In this section, we examine the trading response to the TC related information release using abnormal trading volume, the abnormal number of transactions, and the abnormal percentage of outstanding shares. As stated before, price measures the average consumer response, while trading volume measures different investors' responses. Even when

[1] http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/Data_Library/f-f_factors.html.

one set of information has no value, trading can still be observed due to the fact that investors have different information acquiring capabilities and might interpret the same information differently. In the following, the abnormal value is derived by subtracting the normal value in a *non-event window*, which is from 205 days (i.e., $t-205$) to 5 days (i.e., $t-6$) before the event day t (i.e., announcement of TC adoption), from the value in the event window.

4.1.2.1 Abnormal trading volume Following previous literature [44], based on daily trading volume data from The Trade and Quote, we estimated abnormal total trading volume as follows:

$$\mathrm{AbnVol}_{it} = \frac{\mathrm{Vol}_{it} - \mu\mathrm{Vol}_{i(t-205,t-6)}}{\sigma\mathrm{Vol}_{i(t-205,t-6)}} \quad (5)$$

where Vol_{it}: trading volume of firm i at day t, which is calculated as total number of shares traded on day t, $\mu\mathrm{Vol}_{i(t-205,\ t-6)}$: mean of trading volume of firm i within the non-event window, $\sigma\mathrm{Vol}_{i(t-205,\ t-6)}$: standard deviation of trading volume of firm i within the non-event window.

4.1.2.2 Transactions Number of transactions, like volume, can also be used as a measure of trading. This measurement has been used in earlier literature [40] to measure the change of trading activity of investors to study the information content of annual reports of firms. It can serve two purposes:

1. Validate the volume response documented by abnormal trading volume.
2. When abnormal trading volume is positive (negative), the number of transactions can be used to differentiate between the situation where there are just more (less) trades with basically the same transaction size as before and the situation where there is basically the same number of trades as before, however each transaction is bigger (smaller).

$$\mathrm{AbnTr}_{it} = \frac{\mathrm{Tr}_{it} - \mu\mathrm{Tr}_{i(t-205,t-6)}}{\sigma\mathrm{Tr}_{i(t-205,t-6)}} \quad (6)$$

where Tr_{it}: number of transactions of firm i at day t, $\mu\mathrm{Tr}_{i(t-205,\ t-6)}$: mean of the number of transactions of firm i within the non-event window, $\sigma\mathrm{Tr}_{i(t-205,\ t-6)}$: standard deviation of the number of transactions of firm i within the non-event window.

4.1.2.3 Abnormal percentage of outstanding shares (APOS) While the daily trading volume and the daily number of transactions measure trading on an "absolute" level, meaning not controlling for the potential change of total common share outstanding, daily proportion of shares traded measures such an activity on a relative level. Compared to a non-event day, the APOS method assumes that the proportion of shares outstanding (the number of a firm's shares traded divided by the number of that firm's shares outstanding on a given day) traded around an event day will show a positive increase if newly released information is value relevant. We define APOS as

$$\mathrm{APOS}_{it} = \mathrm{Por}_{it} - \mu\mathrm{Por}_{i(t-205,t-6)} \quad (7)$$

where Por_{it}: proportion of firm i's common shares traded on day t; $\mu\mathrm{Por}_{i(t-205,\ t-6)}$: mean of proportion of firm i's common shares traded within the non-event window.

4.1.3 Relative trading response

As discussed before, the announcement of the adoption of TC technology might be appreciated only by certain groups of investors. In this section, we measure relative trading activity among different investor groups in response to TC technology adoptions using the relative abnormal volume, the relative abnormal number of transactions, and the mean transaction-size. Following prior literature, we use both transaction size [40] and the dollar value of transactions [44] to proxy for investor type and wealth.

4.1.3.1 Dollar value of transactions Bigger, sophisticated investors are considered to be more skilled in acquiring and understanding information than small, less sophisticated ones. To investigate how abnormal trading volume activity varies among investors in response to TC-related announcements, we classify big, medium and small investors using dollar value of transactions following earlier researches [44–46].

Those trades whose dollar value is bigger than or equal to \$50,000 are classified as big trades, those whose dollar value is between \$5,000 and \$50,000 including \$5,000 are classified as medium trades, and those whose dollar value is less than \$5,000 are classified as small trades [44]. However, those trades whose trading price is higher than \$50 and number of shares is less than or equal to 100 shares, are classified as small trades as well [44]. Then, the abnormal trading volume of each group ($\mathrm{AbnVol}_{\mathrm{big}}$ and $\mathrm{AbnVol}_{\mathrm{small}}$) is calculated as follows. For consistency with prior literature [44], we ignore the trading behavior of medium-sized trades:

$$\mathrm{AbnVol}_{j,it} = \frac{\mathrm{Vol}_{j,it} - \mu\mathrm{Vol}_{j,i(t-205,t-5)}}{\sigma\mathrm{Vol}_{j,i(t-205,t-5)}}\ (j \in (\mathrm{big}, \mathrm{small})) \quad (8)$$

Following prior research [40], the abnormal number of transactions of big and small investor groups is also calculated respectively. Big transactions are those transactions whose dollar value is greater than $100,000 ($Tr_{100}$), while small transactions are those whose dollar value is less than $30,000 ($Tr_{30}$). Tr_{100} is interpreted as measures of unexpected institutional investor trading and Tr_{30} as measures of unexpected individual investor trading. The final abnormal transactions of these two specified groups are calculated as Eq. 6.

4.1.3.2 Mean transaction size Unexpected mean transaction size can be used to measure the relative trading activities between well-informed institutional investors and less sophisticated individual investors [40]. As discussed before, compared to individual investors, institutional investors might better understand the valuation of TC. The mean transaction size (MTS) of firm *i* is defined as the number of shares traded per day divided by the number of transactions per day. The unexpected mean transaction size (UMTS1) is defined as:

$$\mathrm{UMTS1}_{it} = \frac{\mathrm{MTS}_{it} - \mu\mathrm{MTS}_{i(t-205,t-6)}}{\mu\mathrm{MTS}_{i(t-205,t-6)}} \qquad (9)$$

where MTS_{it}: mean transaction size of firm *i* on day *t*; $\mu\mathrm{MTS}_{i(t-205,\ t-6)}$: average of the mean transaction size of firm *i* within the non-event window.

UMTS1 can be viewed as a measure of institutional relative to individual investor trading [40]. And a negative (positive) *UMTS1* indicates that individual trading is relatively heavier (lighter) than institutional trading. To capture the relative trading activity by wealthy versus less wealthy individual investors, a special group of transactions whose size is smaller than 900 shares is selected, and the mean transaction size of this group of investors is calculated (UMTS9). And a negative (positive) UMTS9 indicates that trading response among individual investors decreases (increases) with wealth.

4.1.4 Accounting performance

There is a fundamental difference between stock price and accounting performance. While stock price is forward looking, it takes into account the expected future firm performance, accounting is backward looking—it records what has already happened. In this section, using matched sample analysis and multivariate regression, we investigate whether firms that adopted TC technology tend to enjoy better financial performance when compared with a matched control sample of firms, after the adoption year.

Comparing variables of interest across treatment and control groups is a widely used and established research methodology [47–50] and identifying a matching sample fundamentally is an empirical challenge [51]. In the IT valuation studies, researchers have adopted the matching sample analysis methodology to validate their hypotheses [52, 53]. For example, Bharadwaj [52] compares the mean and median financial performances of a portfolio composed of IT leader firms vs. the financial performances of a portfolio composed of non-IT leader firms with similar size in the same industry to investigate whether IT leaders have better current and future financial performance. While replicating the results of early work [52], Santhanam and Hartono [53] observed that the choice of a single firm benchmark could lead to results influenced by selection biases. Furthermore, an industry average is generally considered a better benchmark when a comparison of the financial performance of a set of specified firms is employed [54, 55]. Thus they proposed and used an alternative approach by utilizing all firms, excluding the IT-leaders, in the same industry (4-digit SIC code) as their matching sample group. Due to the above reason, in this study, we adopt methods proposed by Santhanam and Hartono [53] to compare the financial performance of TC technology adopters to their respective 4-digital SIC industry average (excluding the adopters) to answer whether TC adopters enjoy better future financial performance after adoption.

Firm performance can be measured using multi-dimensional financial indicators (e.g., profitability, sales growth), operational efficiency (e.g. asset turn over), or both. An empirically sound approach to evaluate firm performance is to use multi-dimensional indicators [56]. For this purpose, the following financial ratios are utilized to answer our research questions.

Return on Asset (ROA) = *Net Income/Total Assets*: measures profitability.
Profit Margin (ROS) = *Net Income/Sales*: measures profitability.
Asset Turnover Ratio (SOA) = *Sales/Total Assets*: measures utilization and efficiency.

The General Motors model splits ROA into profit margin and asset turnover [57]. Profit margins increase if companies are able to increase gross margins on products and services sold (higher selling price relative to product cost) or improve the effectiveness of sales and administrative inputs. Asset turnover increases if companies are able to utilize their assets more effectively (support greater

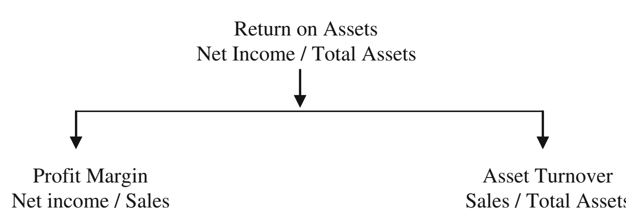


Fig. 2 The general motors model

levels of sales revenue with a certain quantity of assets) (Fig. 2).

Assuming by comparing the mean performances between TCG firms and industry peers, we document that there is a difference, still we could not conclude that TC adoption really leads to better (worse) performance in the future. A potential problem with the above peer group comparison is that the adoption of TC technology might be driven by the historical financial performance. In other words, maybe firms with a better (worse) financial performance are more likely to adopt TCG. So it might be the performance that drives the adoption, not the other way around. Because firms with a better (worse) historical financial performance might enjoy an even better (worse) future financial performance, in such case, it is not the strategy of adopting TC that leads to better financial performance. To control for such a halo effect, following prior research [53], we adopt a multivariate regression approach in which previous financial performance are controlled:

$$\mathrm{ROA}_{t+i} = \alpha_{\mathrm{roa}} + \beta_{\mathrm{roa},1}\,\mathrm{ROA}_t + \beta_{\mathrm{roa},2}\,\mathrm{Dummy}$$
$$\mathrm{ROS}_{t+i} = \alpha_{\mathrm{ros}} + \beta_{\mathrm{ros},1}\,\mathrm{ROS}_t + \beta_{\mathrm{ros},2}\,\mathrm{Dummy}$$
$$\mathrm{SOA}_{t+i} = \alpha_{\mathrm{soa}} + \beta_{\mathrm{soa},1}\,\mathrm{SOA}_t + \beta_{\mathrm{soa},2}\,\mathrm{Dummy}$$

where t is the year when a firm first adopts TC technology, and $t + i$ represents i year after adoption. Dummy is a binary variable and equals 1 for TC technology adopter, and 0 for industry average.

4.2 Hypotheses

Three major hypotheses are set up in this study, stated in null forms (Table 1) to investigate the market response to the announcements of TC technology related events.

The first hypothesis (H1) is to measure the change in investors' expectations regarding the future profitability of a firm. A significant positive AbnR signals that investors value TC and respond with an increasing price, while a significant negative AbnR shows the reality that investors are against TC related technology, and view such announcements as a bad move by a firm. Failing to reject this hypothesis means that consumers do not understand the nature and the future of TC technology and choose to ignore any information related to TC, resulting in price invariance related to the TC information release.

Table 1 Hypotheses (in null form)

Return	Aggregate trading response	Relative trading response
H1: AbnR = 0	H2.1: AbnV ≤ 0	H3.1: $\mathrm{AbnVol}_{\mathrm{big}} \leq 0$
	H2.2: AbnTr ≤ 0	H3.2: AbnVolmedian ≤ 0
	H2.3: APOS ≤ 0	H3.3: AbnVolsmall ≤ 0
		H3.4: AbnTr100 ≤ 0
		H3.5: AbnTr30 ≤ 0
		H3.6: UMTS1 ≤ 0
		H3.7: UMTS9 ≤ 0

The second set of hypotheses (H2) measures the aggregate trading activities in response to TC information releases, which contain abnormal total volume, an abnormal number of transactions, and an unexpected percentage of outstanding shares (APOS) around event days. A significant positive AbnVol or AbnTr or APOS value indicates that investors do value TC technology but their valuations are heterogeneous.

The last set of hypotheses (H3) measures relative trading behavior of different investor groups around the event. Both AbnVol (big and small) and AbnTr (individual vs. institutional) of different investor groups are used to see how different groups of investors vary in responding to the release of TC announcements. A significant negative (positive) UMTS1 suggests that individual investors trade more in response to TC than institutional investors (H3.6). We examine the wealth effect of individual investors in response to TC with hypothesis 3.7. A negative (positive) UMTS9 suggests that the trading response among individual investors decreases (increases) with wealth.

4.3 Data collection

The goal of this study is to investigate the share price and trading behavior of publicly traded firms announcing plans to join TCG, invest in TC technology, including software, hardware, and platform. The first step toward this goal is to identify those firms and the dates of their TC announcements. We use two data sources to search for such events, one is the official website of Trusted Computing Group (TCG) (http://www.trustedcomputinggroup.org) on which most of the announcements for becoming a member, confirming membership, adopting TC technology, or releasing a new product are listed; the other one is Factiva Database which includes major American and international newspapers (up to 9,000 publications worldwide) and is updated on a daily basis. Through these processes, two types of announcements are included in our final samples:

(a) Adoption-related announcements, including news announcing that a firm is adopting TC components or technology, or joining a TC organization to support the further development of TC industry and technology.
(b) Business development announcements, including announcements about the availability of new TC products, upgrades of existing products equipped with TC technology or components, or disclosure of cooperation in producing TC products, or business deals demonstrating that a large amount of products

have been equipped with TC components. We also double-check Factiva to make sure that, within a TC announcement period, starting from 2 days before the event day to 2 days after the event day, there are no other confounding news events. We end up eliminating 17 TC related events which overlap with non-TC related events, such as announcements of merger and acquisition, changing of CEO, and election of company board members.[2]

To get our final list of TC-related announcements, after the above processes, we apply the following to clean up our samples.

1. Because we are interested in how the capital market responds to TC technology adoption, non-publicly traded firms are excluded from our study.
2. Announcements from which a particular firm cannot be identified with certainty are excluded as well.
3. Non US public firms are excluded as well because we do not have access to the capital market data of non-US firms.

Figure 3 shows the distribution of announcements by years. In total, 210 announcements of 98 firms are collected. Most of these firms are active members of Trusted Computing Group.

Table 2 shows the summary of our final sample composed of 124 announcements.

Company financial information was obtained from COMPUSTAT, stock return data were obtained from the CRSP database, while the individual trading data were retrieved from the NYSE TAQ database.

5 Empirical findings

5.1 Price response

We employed both the simple average method and compound method to estimate the aggregate abnormal returns.

$$\text{AbnR}_{i(m,n)} = \frac{1}{n-m+1}\sum_{t=m}^{n}\text{AbnR}_{it}\ (\text{Average Method})$$

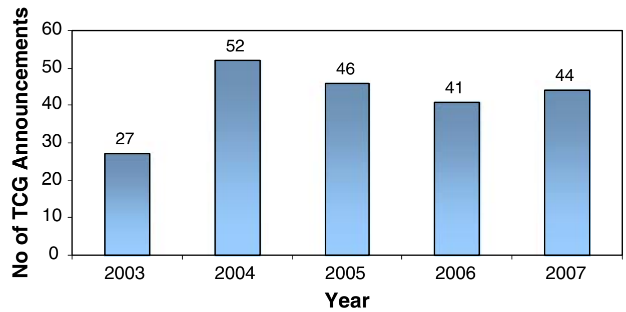


Fig. 3 TC announcements by year, 2003–2004 (N = 210)

Table 2 Summary of sample

Released announcements	210
Less: duplicate announcements	(9)
Less: released by non-public firms	(65)
Less: released by public firms not traded on US stock market	(12)
Final sample size	124

$$\text{AbnR}_{i(m,n)} = -1 + \prod_{t=m}^{n}(\text{AbnR}_{it}+1)\ (\text{Compound Method})$$

Table 3 shows the abnormal returns on a daily basis as well as on an aggregate level, starting from 2 days before the event day (i.e., $t-2$) to 2 days after the event day (i.e., $t+2$).

Overall, regardless of the time window and the estimation methods, the abnormal return is insignificant from zero, failing to reject hypothesis H1. In others words, based on our sample period, we do not find evidence that TC related announcements have information content. In fact, one implicit assumption researchers taken for granted is that an information release lacks information content if price invariance is observed [40]. Our interpretation for the lack of price response is that price invariance indicates that investors might not believe the value relevance of TC technology, which results in no response to the TC related events announcements in the capital market. An alternative explanation is that maybe the price changes are so "small" that we fail to detect them statistically.

5.2 Trading response

Multiple methods are employed to examine the trading response to a TC information release on daily level as well as on aggregate level. Table 4 shows the abnormal volume of the overall market as well that of the big and small investor groups' response. Table 5 reports the market-wide abnormal number of transactions and the abnormal number of transactions of the individual investor group and the

2 Recall that regardless of whether consumers treat TC as favorable or unfavorable, as long as investors have heterogeneous valuation of TC, then we should expect that TC technology related announcements will be associated with increased volume. Hence, trading volume study with confounding events is a conservative test because if we fail to observe an increase in trading volume with confounding events, then it will be even less likely for us to observe a market trading response associated with TC announcement without confounding events.

Table 3 Test of abnormal return

	$AbnR_1$ CAPM model	$AbnR_2$ Fama French model	$AbnR_3$ Fama French adjustment
Event days			
−2	−0.003 (0.2759)	−0.002 (0.4801)	−0.003 (0.3376)
−1	0.0042 (0.2065)	0.0052 (0.1187)	0.0057 (0.1178)
0	−0.002 (0.5716)	−0.002 (0.5781)	0.001 (0.7689)
1	0.0001 (0.9459)	0.0011 (0.5617)	0.0011 (0.6217)
2	0.0007 (0.7747)	−0.000047 (0.9852)	0.0012 (0.6565)
Event window			
Average method			
(−1, 0)	0.0013 (0.5579)	0.0018 (0.399)	0.0032 (0.1625)
(0, +1)	−0.00075 (0.6704)	−0.00024 (0.8898)	0.0024 (0.3429)
(−1, +1)	0.0009 (0.5706)	0.0016 (0.3142)	0.0033 (0.1095)
(−2, +2)	0.000048 (0.9661)	0.0005 (0.6316)	0.0013 (0.2982)
Compound method			
(−1, 0)	0.0025 (0.5736)	0.0036 (0.4163)	0.0071 (0.1619)
(0, +1)	−0.001 (0.6699)	−0.00048 (0.8912)	−0.00088 (0.8176)
(−1, +1)	0.0026 (0.5887)	0.0047 (0.3307)	0.003 (0.4842)
(−2, +2)	−0.000085 (0.988)	0.0024 (0.6771)	0.0034 (0.5949)

Notes: *P* value is in parentheses and two-sided

Table 4 Abnormal volume

	AbnVol	$AbnVol_{big}$	$AbnVol_{small}$
Event days			
−2	−0.139** (0.0243)	−0.158** (0.0338)	0.0333 (0.688)
−1	−0.082 (0.2519)	−0.065 (0.4166)	0.1646 (0.2155)
0	−0.094 (0.3647)	−0.201* (0.0544)	0.062 (0.5593)
1	−0.08 (0.3272)	−0.183** (0.0253)	0.0772 (0.4127)
2	−0.134 (0.1411)	−0.131 (0.2594)	0.0249 (0.8176)
Event window			
(−1, 0)	−0.088 (0.2314)	−0.131* (0.0706)	0.1133 (0.2974)
(0, +1)	−0.087 (0.2811)	−0.198** (0.0143)	0.0696 (0.4479)
(−1, +1)	−0.085 (0.2095)	−0.15** (0.0242)	0.1013 (0.3056)
(−2, +2)	−0.106* (0.0779)	−0.153** (0.0134)	0.0724 (0.4052)

Notes: *P* value is in parentheses and two-sided; * is significant at a *P* value between 0.05 and 0.10, ** is significant at a *P* value of 0.05 or less

Table 5 Abnormal number of transactions

	AbnTr	$AbnTr_{30}$	$AbnTr_{100}$
Event days			
−2	−0.035 (0.6724)	−0.01 (0.9111)	−0.22** (0.0002)
−1	0.0393 (0.6882)	0.0694 (0.4907)	−0.163** (0.0166)
0	0.0226 (0.8282)	0.0578 (0.5807)	−0.193** (0.0206)
1	0.0776 (0.4352)	0.1039 (0.3022)	−0.105 (0.1898)
2	−0.053 (0.6056)	−0.024 (0.8136)	−0.143 (0.1031)
Event window			
(−1, 0)	0.0309 (0.7298)	0.0636 (0.4882)	−0.178** (0.0058)
(0, +1)	0.0051 (0.5742)	0.0809 (0.3747)	−0.149** (0.0249)
(−1, +1)	0.0465 (0.5802)	0.0771 (0.375)	−0.154** (0.0087)
(−2, +2)	0.0104 (0.8889)	0.0395 (0.6101)	−0.165** (0.0028)

Notes: *P* value is in parentheses and two-sided; * is significant at a *P* value between 0.05 and 0.10, ** is significant at a *P* value of 0.05 or less

institutional investor group, while Table 6 depicts the mean transaction size and the proportion of outstanding shares.

On the aggregate level, most of the time the total abnormal trading volume (AbnVol in Table 4) and the abnormal number of transactions (AbnTr in Table 5) are not significantly different from zero on individual days and over different event windows. The abnormal percentage of shares traded (APOS in Table 6) is significant most of the time; however it is significantly negative instead of positive. If TC announcements do have information value, regardless of whether it is viewed positively or negatively, we should expect an increased trading volume around the event day. However, what we actually observed is a decrease in trading activity. A decrease in trading volume means that we fail to find support for TC announcements having information content. Overall since there is no trading response to TC announcements, H2.1 and H2.2 cannot be rejected.

On the relative trading response level, the abnormal volumes of different groups (Table 4) and the abnormal number of transactions of big investors (Table 5) are insignificant from zero except for big investors. The decrease in the abnormal volume of big investors might be caused by the decrease in the number of transactions of

Table 6 Abnormal proportion of shares and mean transaction size

	APOS	UMTS1	UMTS9
Event days			
−2	−0.002** (0.0001)	−0.025 (0.3755)	−0.008 (0.4284)
−1	−0.003** (0.0002)	0.0031 (0.9254)	−0.004 (0.6457)
0	−0.003** (0.0001)	−0.052** (0.0354)	−0.011 (0.31)
1	−0.003** (0.0006)	−0.026 (0.2807)	−0.001 (0.9036)
2	−0.003** (<0.0001)	−0.038 (0.1719)	−0.034** (0.0005)
Event window			
(−1, 0)	−0.003** (<0.0001)	−0.024 (0.3107)	−0.008 (0.3515)
(0, +1)	−0.003** (<0.0001)	−0.039** (0.0620)	−0.006 (0.4662)
(−1, +1)	−0.003** (<0.0001)	−0.025 (0.2458)	−0.006 (0.4735)
(−2, +2)	−0.003** (<0.0001)	−0.028 (0.1725)	−0.012 (0.1022)

Notes: *P* value is in parentheses and two-sided; * is significant at a *P* value between 0.05 and 0.10, ** is significant at a *P* value of 0.05 or less

institutional investors (the significant negative $AbnTr_{100}$ in Table 5), which is consistent with the decrease in the size of each transaction (UMTS1 < 0 on the event day but insignificant on the other days in Table 6). The negative *UMTS1* represents the situation where there are either fewer big investors or more small investors engaged in the trading. This supports our former findings (APOS < 0). Given that both $AbnVol_{small}$ and $AbnTr_{30}$ are not significantly different from zero, while $AbnVol_{big}$ and $AbnTr_{100}$ are significantly less then zero, we believe it is very likely that the relatively fewer trades from big or institutional investors, instead of relatively more trades from small individual investors, led to a decrease in the proportion of common shares outstanding traded. Furthermore, except on day $t + 2$, for most of the time, the UMTS9 of Table 6 is not significantly different from zero either. All these lead to one conclusion: regardless of investor group (institutional vs. individual) or individual investor wealth status (wealthy vs. less wealthy), investors valuate and respond in similar ways to TC announcements. For big investors, such announcements have even less information content. Overall, within our sample periods, we fail to find evidence that TC is value relevant and TC announcement has information content to either the market as whole or to different types of investors. The hypothesis series 3 (from 3.1 to 3.7) cannot be rejected either.

Even though within our sample period, we fail to find an increased market response to the adoption of TC for our overall sample, this does not necessarily mean that TC is not value relevant. Market response to TC might be limited to a certain group of firms. To address this issue, based on the nature and time of TC adoption as well as the industry of the adopters, we classify our firm events into different groups, such as manufacturing firms versus service firms, hardware related TC adoption versus software related TC adoption, early adopters versus later adopters, and qualitatively our results do not change. Regardless of the nature of the TC adoption, the time of the adoption, or the industry of a firm, we still do not observe abnormal earnings or an abnormal trading response to the adoption of TC. Furthermore, such patterns hold for different types of investors as well. The only difference we observe is that for companies in the service industry, there seems to be a weak positive price response 1 day before a TC announcement (at 90% confidence interval); while for companies in the manufacturing industry, we see a weak negative market response on the TC announcement day (at 90% confidence interval). We interpret this to mean that it would be hard for consumers to appreciate the value of TC if that TC technology is not linked to any service, and the value provided by naked TC hardware without immediate application might be perceived by investors as trivial, at least for our sampling periods.

5.3 Change of accounting performance

Table 7 shows both the mean and median results of the performance comparison between firms adopting TC technology and their related industry peer group. As elaborated in Sect. 4.1, for each TC firm, its peer group's financial performance is defined as the average financial performance of its respective industry (excluding the TC adopters) based on 4-digital industry classification code SIC. Then we investigate whether on average TC firms enjoy better financial performance as compared to their industry peers. Such a comparison is conducted over a specific window beginning 2 years before the year of TC adoption and ending 2 years after the year of TC adoption. Due to a data limitation of *Compustat*, we lose some observations for year $t + 1$ and year $t + 2$ for those firms adopting TC in 2005 or 2006.

Both a parametric *t* test (reported as Mean and *T*-statistics) and a non-parametric Wilcoxon rank test (reported as Median and *Z*-statistics) are employed to examine the

Table 7 Performance comparison between TC firms and matched peer group 2 years before adoption year

		N	Mean	Median	T value	Z value
ROA	TC firms	31	−0.132	−0.013	−2.05**	3.803**
	Peer group	31	−0.257	−0.239		
ROS	TC firms	31	−0.157	−0.013	−2.16**	3.515**
	Peer group	31	−0.316	−0.323		
SOA	TC firms	31	0.755	0.627	1.850**	−2.865**
	Peer group	31	0.951	0.899		
1 year before adoption year						
ROA	TC firms	31	−0.119	−0.014	−1.380	2.951**
	Peer group	31	−0.197	−0.213		
ROS	TC firms	31	−0.150	−0.018	−1.26	2.778**
	Peer group	31	−0.239	−0.252		
SOA	TC firms	31	0.727	0.6072	2.58**	−3.485**
	Peer group	31	0.984	0.9258		
Adoption year						
ROA	TC firms	31	−0.058	0.024	−1.82**	4.113**
	Peer group	31	−0.152	−0.153		
ROS	TC firms	31	−0.062	0.024	−1.99**	3.549**
	Peer group	31	−0.177	−0.185		
SOA	TC firms	31	0.748	0.639	2.64**	−3.141**
	Peer group	31	0.987	0.946		
1 year after adoption year						
ROA	TC firms	28	−0.009	0.0533	−2.45**	4.697**
	Peer group	28	−0.128	−0.140		
ROS	TC firms	28	0.0225	0.0538	−2.95**	4.566**
	Peer group	28	−0.125	−0.135		
SOA	TC firms	28	0.8234	0.7129	1.50	−3.139**
	Peer group	28	0.988	0.9510		
2 year after adoption year						
ROA	TC firms	23	−0.007	0.0437	−1.76**	4.134**
	Peer group	23	−0.102	−0.093		
ROS	TC firms	23	0.012	0.0761	−1.92**	4.046**
	Peer group	23	−0.104	−0.109		
SOA	TC firms	23	0.8139	0.8023	1.73**	−1.869**
	Peer group	23	0.9547	0.9290		

Notes: P value is in parentheses and two-sided; * is significant at a P value between 0.05 and 0.10; ** is significant at a P value of 0.05 or less

difference between the treatment (the TC adopters) and control samples (the average of their respective industry peers within the same 4-digital SIC). The reason for including both a parametric T-test and the non-parametric rank test is that the financial ratios might not be normally distributed. Hence, compared to using the mean as the performance measure, the medians are considered to be a better performance indicator which is robust to outliers and underlying statistical distribution assumptions [52].

Table 7 shows that compared to their industry peers, TC firms enjoy a better ROA and profit margin (ROS), and worse asset turn over ratio (SOA), before adoption ($t-2$ to $t-1$), at adoption (year t), and after adoption ($t+1$ to $t+2$). The test results are reported as either T-statistics (parametric comparison) or Wilcoxon Rank Sum Z-statistics (none-parametric difference). Figure 4 is a visual representation of Table 7, year 0 means the year that TC was

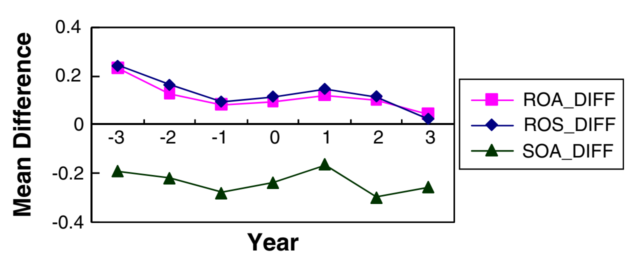


Fig. 4 Performance difference between TC firms and their peer groups

Table 8 Regression result

	N	Related financial performance at adoption		
		Intercept	Year	Dummy
1 year after adoption				
ROA_{t+1}	56	−0.0235 (0.3965)	0.6266** (<0.0001)	0.0537 (0.1293)
ROS_{t+1}	56	−0.0092 (0.7450)	0.5985** (<0.0001)	0.0651* (0.0716)
SOA_{t+1}	56	−0.0006 (0.9934)	1.0121** (<0.0001)	0.0574 (0.2791)
2 years after adoption				
ROA_{t+2}	46	0.0163 (0.4278)	0.7226** (<0.0001)	0.0284 (0.2797)
ROS_{t+2}	46	0.041* (0.0805)	0.7404** (<0.0001)	0.02 (0.495)
SOA_{t+2}	46	0.1909** (0.0081)	0.7961** (<0.0001)	0.04 (0.344)

Notes: *P* value is in parentheses and two-sided; * is significant at a *P* value between 0.05 and 0.10, ** is significant at a *P* value of 0.05 or less

adopted, and year 2 means 2 years after the adoption, and so on. ROA_DIFF (ROA of TC firms minus ROA of control groups) and ROS_DIFF (ROS of TC firms minus ROS of control groups) are above zero before firms adopt TC technology; while SOA_DIFF (SOA of TC firms minus SOA of control groups) is below zero. To summarize, TC adopters seem to have better historical performance than their industry peers before and after adoption. However, after adoption, as time moves on, the performance gap between these two groups (adopters vs. their peers) becomes narrower instead of wider. Thus, no concrete conclusion can be drawn at this moment. It seems more likely for firms with better financial performance (ROA and ROS) to adopt TC technology; however, such an adoption does not lead to an improved future financial performance.

Table 8 shows the regression results with the historical financial performance controlled. The results indicate that firms with better historical financial performance do continuously enjoy a better future financial performance, supporting the argument that in order to draw meaningful conclusions, we need to control the historical financial performance of TC adopters. At 95% confidence interval, in both 1 and 2 years after TC, neither of the dummy variables in these three models is significantly different from zero. Pooling all these results together, with previous financial performance controlled, we can see that the adoption of TC has no immediate financial impact.

6 Conclusions and discussions

According to event study methodology, for the announcements with information value, good (bad) news is associated with positive (negative) share price reactions. Our study finds price invariance on the announcements disclosing TC technology related adoption, indicating that TC technology announcement has no information content.

Results consistent with the price result are also found when examining trading activities. On the aggregate level, no significant results are found by either overall trading volume or the number of transactions test (failure to reject Hypothesis H2.1 and H2.2). Even though the abnormal percentage of outstanding shares (APOS), the abnormal trading of big investors ($AbnVol_{big}$) or institutional investors ($AbnTr_{100}$) are significantly different from zero, their values are smaller instead of bigger than zero. This again indicates that TC technology announcements lack information content. A negative UMTS1 on event days supported by a decreasing trading volume and a decreasing number of transactions by big investors or institutional investors indicate that big or institutional investors trade even less when there are TC announcements. We also fail to find evidence that TC announcements are value relevant for individual investors, regardless of their wealth status (wealthy vs. less wealthy). To conclude, in response to TC announcements, no sign of price response or higher trading activity has been found in this study (Table 9).

Table 9 Summary of results

Return	Aggregate trading response (no trading response)	Relative trading response (no relative trading difference)
AbnR = 0	AbnVol = 0	$AbnVol_{big} \le 0$
	AbnTr = 0	AbnVolmedium = 0
	APOS < 0	AbnVolsmall = 0
		AbnTr100 = 0
		AbnTr30 = 0
		UMTS1 < 0
		UMTS9 = 0

Facing the fight between proponents and opponents of TC technology, this study investigates the valuation of TC issues from capital market and financial performance perspectives. We document that the fast growing Trusted Computing Group and huge investments in TC technology are rewarded with an indifferent response from the stock market. This paradox is explained when we examine the accounting performance impact of TC adoption. Our results fail to show that firms receive any extra accounting benefit after adopting TC technology, which might explain the price invariance and volume invariance we observed in the stock market.

In the literature, researchers have successfully used event study methodology to document the value impact of IT investments. So, why can we not document the value of TC using event study methodology in our study? Is this another story of IT paradox in which firms invest huge amounts in TC but with limited, if not negative financial gain? We have run an exhaustive search for some small evidence that might reveal the value of TC, unfortunately the results are very disappointing.

So what next? Does this mean that the fate of TC is doomed? The answer is no. Even though TC does not impact accounting performance 1 year after adoption, there might be a lag effect; in other words, it might take many years before firms can realize their investment in TC. If there were a lag between the costs and benefits of IT, then research that relates earnings to contemporaneous IT spending would not detect the performance impact of IT spending [42]. Assimilation has been identified as an important construct in the causal chain that separates the adoption of IT from its impact on firm performance [58–61].

Then why do not investors get the picture? Is not the stock market an efficient market? Is not the stock market supposed to reflect this long-term performance impact? We believe that the real answer is education. TC itself is complicated and hard to be appreciated and digested by end-consumers. Facing the uncertainty of the functionality and future prospects of TC, consumers might just choose to ignore TC related announcements. So, in order to make TC successful, vendors need to put more emphasis on educating end consumers about the potential costs and benefits of TC technology. Before consumers can really wake-up and understand the value of TC, they will continue falling asleep. The other reason for market silence might be driven by the limited availability of applications supported by TC. Without such applications, it is going to be very hard for consumers to digest the value of TC with TC-enabled hardware alone. Do we know which side will wake the consumers up? Or are they going to fall asleep forever?

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