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Supply chain security certification and operational performance: The role of upstream complexity

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ABSTRACT

Supply chain security (SCS) incidents increasingly cause financial losses to manufacturing facilities and logistics service providers. Thus, supply chain security certification can have implications for production economics, particularly for importing firms who rely on a smooth logistics flow across country borders. However, it largely remains unknown regarding how such certification could influence a firm's operational performance. To this end, we empirically examine whether and how the adoption of Customs-Trade Partnership Against Terrorism (C-TPAT) certification, initiated by the U.S. Customs and Border Protection (CBP), could improve operational performance in adopter firms. This study draws upon signaling theory to empirically investigate the value of C-TPAT certification on U.S. publicly-traded *importer* firms' operational performance by analyzing the longitudinal data of properly-matched sample-control groups. The data come from multiple sources: public announcements of C-TPAT certification from the News Retrieval Service database, import data from lading records, and financial data from Standard & Poor's COMPUSTAT database. Employing a coarsened exact matching (CEM) method and a difference-in-difference (DID) analysis, we find that C-TPAT certified importers have better operational performance than that of non-certified importers. We also find that the level of upstream supply chain complexity (*detail*, *dynamic*, and *spatial* complexity) enhances the operational performance derived from C-TPAT certification. This study sheds light on the performance value of a management standard that is attributed to the non-process mechanism (not due to *process* improvements) enabled by the signaling effectiveness incorporating the upstream supply chain complexities. Our findings have important theoretical and practical implications for production economics and supply chain management studies.

"*The bombings of two shipping and transportation hubs in Brussels are evidence that securing global supply chains is still integral to safeguarding the lives of people around the world and maintaining the stability of the global economy*."

- "Heightened Supply Chain Security in the Shadow of Risk", *Sourcing Journal*. (March 25, 2016)

1. Introduction

Growing international production, sourcing, marketing, and trading activities have brought a variety of risks to supply chain security (SCS) management. In particular, production facilities and logistics processes are vulnerable to security incidents (Su et al., 2021). Numerous SCS incidents such as terrorist attacks, importation of prohibited weapons, and drug smuggling have occurred worldwide and consequently affected public safety, national security, and economic prosperity. Supply chain security incidents have caused both financial and productivity losses to supply chain partners (Lu et al., 2017; Tang 2006). The suicide bombing attacks cited above caused over 30 deaths and seriously damaged supply chain infrastructure (airport and highway station), resulting in subsequent delays in transportation. In addition to these catastrophic incidents, numerous other SCS incidents have occurred to cause financial losses and threaten human health and lives (Hintsa et al., 2009; Peleg-Gillai et al., 2006). For instance, the number of thefts at warehouses, container terminals, and cargo transits has been

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continuously increasing (*Security Magazine*, April 1, 2016). In 2020, almost twice as many cargo thefts at container terminals or in cargo transits occurred as in 2019 in Texas of the U.S. alone (2020 Supply Chain Risk Trends Analysis). The goal of securing a supply chain lies in promoting an efficient flow of legitimate business while mitigating SCS risks inherent in the contemporary complex and dynamic global business environment (Thibault et al., 2006). Consequently, public and private sectors respond by implementing security management practices to enhance SCS within firms and across their supply chains.

The 9/11 incident prompted the U.S. government to overhaul its security strategies to heighten the security level across international and domestic supply chains. The U.S. government has devoted special attention to *inbound* transportation through the seaport because this is the channel most favored by terrorists for importing hazardous goods such as illegal weapons or drugs (the U.S. Customs Border Protection, henceforth CBP). Seaports have become the most vulnerable locations because of the high volume and variety of import goods passing through them. The war on terrorism must be fought by various stakeholders, such as the business community, which desires a secure environment in which to transact business, and government agencies, whose primary duties pertain to the maintenance of economic prosperity by providing security to society (Sheffi 2001). Lu and Koufteros (2019) classified supply chain security practices into four categories (i.e., detection, prevention, response, and mitigation) and further found that firms adopting more integrated approaches realized superior performance. Among various SCS initiatives, the Customs-Trade Partnership Against Terrorism (C-TPAT) certification is the most widely adopted SCS enhancement program among firms. This certification was developed by the CBP to enhance the ability of adopter firms to manage SCS risks. C-TPAT focuses on security enhancement, responsibility compliance, and the building of a cooperative bond between the CBP and C-TPAT certified firms, highlighting the threat to U.S. border security from high-risk cargoes. To be C-TPAT certified, firms must demonstrate a continuous commitment to improving SCS. Certified firms can receive "fast lane" treatment in the customs clearance process, and reduced (or no) customs inspection. More importantly, C-TPAT certification represents firms' commitment to SCS and a clear signal that the operations within those firms and across their supply chain boundaries are secure. Such commitment aligns with the general goal of international trade of keeping the supply chain secure in order to enable a connected world with less "boundary restrictions in terms of goods and services" (Hassija et al., 2020). To this end, we seek to ask the first research question: *whether and how C-TPAT certification could improve operational performance in adopter firms.*

Signaling theory suggests that to reduce information asymmetry, one party (the signaler) can send favorable signal processing information about itself to others (receivers) who cannot observe the information directly (Connelly et al., 2011). The perspective of signaling theory explains how firms would benefit from signaling positive messages (e.g., commitment to SCS) to their stakeholders, whereas receivers can use the signal to differentiate signalers from others, resulting in improvement of operational outcomes for the signalers (i.e., the firms). Prior studies have argued that the adoption of standard certification is a valid signaling behavior (e.g., Terlaak and King 2006), which helps certified firms secure legitimacy and generate competitive advantages.

Firms increasingly recognize the importance of mitigating SCS risks in a complex supply chain environment. Previous studies assert that recent technological developments such as Artificial Intelligence and Blockchain can effectively mitigate supply chain security risks in firms' operations (Epiphaniou et al., 2020; Hassija et al., 2020; Hastig and Sodhi 2020). However, to the best of our knowledge, research on the effect of supply chain-level complexity on supply chain security is scant. In particular, when firms compete internationally, they need to consider the complexity inherent in managing their global supply chains. For example, a news article in the *Financial Times* (January 25, 2016) discussed how an increasingly complex supply chain affects firms' strategies in mitigating risks caused by the globalized economy, revealing that "companies blamed the complexity of their supply chains and the inadequacy of supplier responses to their own enquiries." Complexity can occur in various ways in the management of a global supply chain. Signaling theory suggests that because the signal (sent by the signaler) contains favorable information regarding the signaler, it can be beneficial for the signaler to reduce information asymmetry between itself (e.g., a certified firm) and the receivers (e.g., stakeholders) (Connelly et al., 2011; Heil and Robertson, 1991; Porter, 2008; Rindova and Fombrun 1999). Moreover, we demonstrate that the positive operational performance resulting from signaling C-TPAT certification varies across the levels of upstream supply chain complexity.

Recent studies have highlighted upstream complexity as a critical contingency in influencing supply chain management (Bode and Wagner 2015; Bozarth et al., 2009). In managing importing security which relies on firms' smooth communications and coordination with suppliers in activities such as packaging, containerization, documentation, insurance, storage, and importing and exporting regulations, the influence of upstream complexity should not be neglected. The second research question of this study examines whether and how upstream supply chain complexity affects the effectiveness of C-TPAT certification as a signal to convey firms' commitment to SCS to stakeholders. Specifically, we seek to answer the question: *Whether the complexity inherent in the interface between firms' importing activities and their upstream supply chains influences the performance value created by the signaling effects of C-TPAT certification.*

We organize the remaining sections as follows. Section 2 reviews related literature to inform our hypothesis development. Section 3 develops our research hypotheses. We discuss the research method and data analyses in Section 4. Finally, section 5 provides theoretical and practical implications of this study.

2. Literature review

2.1. Management standards and operational performance

Extant studies on the performance value of management standards such as ISO 9001 for quality management and ISO 14001 for environment management provide mixed findings. For example, a large body of research has found significant and positive relationships between management standard adoptions and firm (or plant) operational performance (e.g., Corbett et al., 2005; Lo et al., 2014), while some studies have found insignificant relationships (e.g., Heras et al., 2002, Martínez-Costa et al., 2009).

Although these studies provide fruitful insights on the values of management standard implementations, they may also be prone to the following limitations: (1) Some studies drew conclusions based on a very small sample size; (2) Many studies used self-administered survey research based on perceptual measures where the selection bias has not been satisfactorily addressed (e.g., Whipple et al., 2009); (3) A stream of research used second-order performance metrics (i.e., financial performance) instead of first-order metrics (i.e., process compliance such as quality improvement) to account for the effects of *process* management standards. This seems problematic because "second-order performance improvements also may be attributed to other non-operational factors, such as 'signaling', in which the certified company is treated more favorably by its customers and by the stock market, regardless of any realized, process-level benefits of certification" (Gray et al., 2015, p.3).

Given that C-TAPT certification improves the relationships between certified firms and stakeholders (e.g., U.S. CBP and customers) by providing direct and tangible advantages rewarded by the U.S. Customs and strengthening customers' confidence in adopter firms' SCS management, rather than focusing on how management practice (i.e., C-TPAT) can be utilized as a resource (i.e., RBV) for competitive advantage, this study takes a signaling theory perspective which fits better within the C-TPAT context. In addition, it should be noted that unlike

ISO 14001 and ISO 9001, C-TPAT certification provides a direct and tangible benefit, i.e., faster customs clearance at the borders. Therefore, this study contributes to the extant literature on management standards adoptions by theorizing the mechanism concerning the causal relationship between C-TPAT adoption and firm's operational performance, and empirically investigating the extent and the circumstances under which firms can reap the best outcomes.

2.2. Supply chain security research

In view of the widespread recognition of SCS management, researchers have investigated the motivations (e.g., institutional forces) for the adoption of C-TPAT certification (e.g., Lun et al., 2008), established conceptual models to analyze security initiatives (e.g., Russell and Saldanha 2003), or employed a mathematical modeling approach to optimize the inspection level to minimize the costs of SCS implementation (e.g., Bakshi and Gans, 2010). These studies not only explain the importance of SCS, but also provide implementation guidelines for practitioners. In addition to these studies, we use objective empirical evidence to complete the research into whether and how an SCS standard certification could improve operational performance by incorporating upstream supply chain complexity.

In addition, C-TPAT has significant security and throughput implications for U.S. customs and importer firms. The current SCS literature mainly focuses on the universal implications of SCS practices for all firms without differentiating the context for which these practices are originally designed. That is, C-TPAT provides direct benefits for importer firms in the customs clearance process (e.g., less inspection, priority for inspection, or exemption from inspection). The effectiveness and contingency of C-TPAT implementation may have critical managerial implications for the U.S. government and individual importer firms. Prior studies have failed to document such differences in their analysis of the impact on firm performance.

2.3. Signaling theory

Porter (2008) suggests that "a signal is any action by a competitor that provides a direct or indirect indication of its intentions, motives, goals, or internal situation" (p. 75). Such signals inform market participants about a firm's (competitive) intentions (Heil and Robertson, 1991). Thus, signals communicate to stakeholders the value that a firm is creating for them (Rindova and Fombrun 1999). A signal is useful for reducing "information asymmetry" between two parties such that the signaler can convey its latent and unobservable attributes to the receivers through signaling behavior (Connelly et al., 2011). The signaling theory has been applied in a variety of management literature such as human resource management (e.g., Suazo et al., 2009), operations/supply chain management (e.g., Sarkis et al., 2011), strategic management (e.g., Reuer and Ragozzino 2012), entrepreneurship (e.g., Janney and Folta 2003), organization behavior (e.g., Terlaak and King 2006), etc. For example, Reuer and Ragozzino (2012) investigated how signals of initial public offerings (IPOs) affect other firms' choices of governance (joint venture vs. acquisition). Their study shows that asymmetric information plays a critical role in influencing firms' acquisition deals and mitigating adverse selection. The value of signals is heterogeneous depending upon the characteristics of exchange partners, suggesting that strategic alliances should take signaling effect and firm contingency (e.g., prior experience) into account. In addition, Terlaak and King (2006) empirically examined the impact of ISO 9000-certified facilities from a signaling perspective. They argue that ISO 9000 certification helps adopter facilities obtain a competitive advantage through signaling their capability to produce high-quality products. However, the positive effect of signaling is moderated by how buyers encounter difficulties in acquiring information about suppliers. In other words, management standards would help firms convey unobservable attributes to their stakeholders, providing indirect benefits through the "implications of the firm's capability" from the signal. In addition to these indirect advantages, C-TPAT certification offers direct advantages to adopters (e.g., faster border crossing in U.S. Customs). Therefore, the signaling through C-TPAT adoption of their SCS capability is likely to bring performance value to the adopter firms. More recently, using the signaling theoretical perspective, Kim and Wagner (2021) studied how stock market reacts to corruption risk in upstream suppliers versus downstream customers. Chod et al. (2020) compared the benefits of signaling quality information through inventory transactions with loan requests in the context of blockchain-enabled supply chain management.

2.4. Upstream supply chain complexity

Signaling is particularly important in a complex environment because the signal can reduce the search time and cost for a supplier or a business partner (Connelly et al., 2011; Terlaak and King 2006). Complexity in the operating environment is a broad research area in management studies (Anderson 1999). Recent studies have begun to focus on supply chain network complexity and how it affects firms' operational performance (e.g., Choi and Hong 2002; Bozarth et al., 2009). A complex adaptive system (CAS) perspective is applied to supply chain management studies to understand how individuals adapt to the complex environment (Choi et al., 2001; Schneider and Somers 2006). Several scholars have argued for the need to research complexity in supply chain and operations management issues (Bode and Wagner 2015; Vachon and Klassen 2002).

There are many definitions of supply chain complexity. Vachon and Klassen (2002) suggested that supply chain complexity has two dimensions – form of technology and nature of information processing – both of which affect delivery performance (delivery speed and reliability). Their findings suggest that lowering the degree of complexity could improve delivery performance. Supply chain complexity can also be classified as: *upstream*, *internal manufacturing*, and *downstream* complexity (see Bozarth et al., 2009). Choi and Hong (2002) suggested that *structural* complexity in the supply chain is composed of *horizontal* (the total number of individuals within the same level), *vertical* (the number of levels in the system), and *spatial* (the degree of dispersion among individuals in the system) complexity. In addition, from a dynamic perspective, complexity is categorized into *detail* and *dynamic* complexity, whereby the former refers to "distinct number of components or parts that make up a system" while the latter means "the unpredictability of a system's response to a given set of inputs" (Bozarth et al., 2009).

This study focuses on the effect of C-TPAT certification on importing security in firms' upstream logistics flows (e.g., customs clearance) and their extended supply chain operations. Prior studies have also suggested that upstream supply chain complexity affects supply chain performance (e.g., Bode and Wagner 2015). Following this line of research, we study the *upstream* complexity associated with the signaling benefits from C-TAPT certification adoption. Considering that the importing dynamics associated with supplier portfolios in upstream supply chains can introduce complexity, we employ the widely-adopted definition of supply chain complexity in Bozarth et al. (2009), which is "the level of detail complexity and dynamic complexity exhibited by the products, processes, and relationships that make up a supply chain." Thus, we examine how *detail* and *dynamic* complexity in firms' upstream supply chains influence signaling benefits. Since the origins of import goods vary significantly, it is difficult for stakeholders to interpret the value of C-TPAT signals. In addition to *detail* and *dynamic* complexity, we conceptualize the source diversity of per-unit import goods as the *spatial* complexity (see Section 4.3). This conceptualization of supply chain complexity is similar to Bode and Wagner's (2015) spatial complexity of "geographical spread of an organization and/or a supply base."

3. Hypotheses

3.1. The impact of C-TPAT certification

Many firms already have security routines before adopting C-TPAT. To obtain the certification, candidate firms need to implement and internalize additional security measures required by the certifying body (i.e., the CBP) and strive to integrate all these security routines into a coherent whole (Lu and Koufteros, 2019; Ritchie and Melnyk, 2012). Stakeholders (supply chain partners or customers) use the C-TPAT-certified signal to understand a firm's efforts in implementing extensive security measures. Because of the objective third-party audit, C-TPAT certification is a credible, visible, and effective instrument to signal a firm's commitment to SCS management and its potential capabilities in managing SCS.

C-TPAT certification provides a clear signal to the market and the CBP that the certified firm is paying attention to the potential security risks in its supply chain management, particularly in relation to safely importing and distributing goods. Some businesses trade in valuable and high-tech products that are highly *security-sensitive.* These firms prefer to partner with highly reliable firms with lower security risks. For example, pharmaceutical companies and the Food and Drug Administration (FDA) urge transport service providers to be security conscious because prescribed medicines may be hijacked in transit or in warehouses, leading to illegal drug dealing in gray markets. Stakeholders encounter difficulties in identifying reliable firms that are committed to SCS management standards because searching such partners is costly.

Under increasing stakeholder pressure to demonstrate their commitment to SCS, firms may consider adopting C-TPAT certification to signal their unobserved competence in SCS management. However, such certification requires considerable investment in incorporating security standards into firms' daily routines. Specifically, C-TPAT certification costs incurred by importers are estimated to average 55,100 USD at the early stage of certification (Thomasnet.com. January 23, 2014), including implementation costs (e.g., IT system/database development) and C-TPAT maintenance costs (e.g., personnel hired for maintaining C-TPAT). Riskier firms (firms with a low level of security management implementation and security awareness) would incur higher implementation costs, because more work and changes are required to fulfill the audit requirements. Riley (2001) suggests that the cost of implementing management standards is negatively related to the *ex ante* management performance in the firm. That is, it is possibly more costly for firms with "below-average" SCS performance to adopt C-TPAT than firms with "above-average" SCS management.

Consequently, certification is likely to be only beneficial for "above-average" firms, incentivizing "above-average" firms to seek certification, while "below-average" firms are less motivated to do so. This logic echoes Terlaak and King's (2006) point that "*certification must be advantageous only for the high quality ones*." Therefore, certified firms could leverage C-TPAT certification as an effective signal to convey their commitment to SCS to the stakeholders by reducing supply chain partners' *adverse selection* risk (Jażdżewska-Gutta et al., 2020; Reuer and Ragozzino 2012) and increasing the confidence of supply chain partners in focal firms' security management. The C-TPAT certification can be rewarded by preferences (e.g., for products or services) for certified firms by their stakeholders.

Accordingly, we argue that establishing an enhanced security regime through C-TPAT certification will benefit firms, enabling them to save costs and develop confidence among stakeholders. This advantage is more beneficial for firms with an *ex ante* "above-average" level of commitment to SCS in meeting the stringent criteria for C-TPAT certification than for firms with "below-average" commitment to SCS. Therefore, the expected operational benefits from adopting C-TPAT certification can motivate "above-average" (i.e., high commitment-to-SCS) firms to pursue the C-TPAT certification while "below-average" firms may be inhibited from adopting the certification. Moreover, importers can use C-TPAT certification to signal their SCS commitment to U.S. CBP and receive "fast lane" priority, less inspection, or exemption from inspection advantage in the customs clearance process. As evidenced by practitioners that "*The importer of record needs to identify if the reduction in shipping problems due to C-TPAT registration has a greater dollar value than the implementation costs. But organizations now registered in C-TPAT are, in fact, seeing positive results in their total landed costs*" (Thomasnet.com. January 23, 2014), C-TPAT certification offers advantages to certified firms through signaling their commitment to SCS to their stakeholders, thus increasing orders from customers and reducing supply chain disruption costs (e.g., delayed shipments). Taken together, the benefits of C-TPAT certification adoption would help firms increase profitability and sales growth.

H1. *C-TPAT certification adoption positively affects firms' profitability (i.e., ROA).*

H2. *C-TPAT certification adoption positively affects firms' sales growth.*

3.2. The effect of upstream supply chain complexity

Although C-TPAT may bring performance benefits to adopting firms by signaling C-TPAT certification, the effectiveness of these signals can be contingent upon the varying levels of upstream supply chain complexity of the importer firms. Prior studies have demonstrated that the operational benefits created by signaling are apt to vary across supply chain characteristics (see e.g., Chod et al., 2020; Narasimhan et al. 2015). Similarly, C-TPAT certification aims at streamlining the *upstream* supply chains for importer firms (i.e., faster lane priority, less inspection or exemption from inspection for C-TPAT adopters by U.S. Customs). Specifically, in the customs clearance process, goods delivered to the "notify" or "consignee" party (importer) that is C-TPAT certified can be subject to the above-mentioned advantages. As a result, the complexity embedded in upstream supply chains, specifically in the coordination between suppliers and importers in managing SCS, is likely to affect the operational benefits created by signaling C-TPAT. Consider, for example, that if one importer experienced a significant increase in the number of overseas suppliers in a focal year (the country of origin may also vary), the importing procedures would be more complicated in the customs clearance process.

In this study, we examine three types of complexity in the upstream supply chain, namely *detail*, *dynamic*, and *spatial* complexity, which are well-theorized in the literature (see Choi and Hong 2002; Bozarth et al., 2009; Sharma et al., 2020) in influencing the effectiveness of signaling SCS commitment through C-TPAT certification. Although there are many other dimensions of supply chain complexity in the literature, we argue that the three types of complexity in upstream supply chains fit better within the context of C-TPAT. Specifically, *detail* complexity means the "distinct number of components or parts that make up a system" (Bozarth et al., 2009), *dynamic* complexity refers to "the unpredictability of a system's response to a given set of inputs, driven in part by the interconnectedness of the many parts that make up the system" (Bozarth et al., 2009), and *spatial* complexity is referred to as the "degree of dispersion among members within the system" (Choi and Hong 2002).

We argue that firms with a high level of upstream supply chain complexity (*detail*, *dynamic*, or *spatial*) can better utilize C-TPAT certification to signal their commitment to SCS, thus enabling them to generate greater marginal revenues than firms with a low level of complexity. The accorded advantages of C-TPAT certification become strong incentives for importer firms with a high level of upstream supply chain complexity. Shorter custom clearance times can reduce variability and risk inherited from the complexities of firms' internal and external operations (Bowersox et al., 2002; Lee and Whang 2005; Sharma et al., 2020). Firms with a high level of complexity would tend to adopt C-TPAT from a *rational* perspective (*rational* adoption). In other words, these firms are more motivated to pursue certification for operational benefits, as this brings scale-economy advantages in cargo movement for trading. It increases marginal revenues derived from faster cargo flows, priority in customs clearance, and a better relationship with the CBP, which can help effectively mitigate risks caused by supply chain complexity.

Rational adoption may lead to *separating* equilibrium (see Gibbons 1992), where the signals regarding SCS management can be interpreted differently by stakeholders according to the level of supply chain complexity. In contrast, it appears that firms which have a low rather than a high level of upstream complexity may pursue C-TPAT certification due to *coercive* pressure or to mimic adoption behavior (e.g., Jennings and Zandbergen 1995; Verhaal et al., 2017) in order to meet the minimal requirements of the institutional environment (*coercive* adoption). For example, as buyer firms increasingly require transport carriers and suppliers to be C-TPAT-certified, firms with a low level of upstream complexity are under pressure to adopt the certification. Accordingly, they may ambiguously signal C-TPAT certification to stakeholders through *coercive* certification without acknowledging the true value of the certification. That is, the *coercive* adoption may lead to *pooling* equilibrium (see Gibbons 1992), whereby stakeholders cannot easily interpret the signals to distinguish between firms' SCS management, as if all firms had chosen to adopt C-TPAT. Hence, *coercive* certification could not enable their stakeholders to distinguish their own intended commitment to SCS from that of others. Collectively, the signaling benefits from *rational* adoption of C-TPAT certification (motivated by high complexity in the focal firm's upstream supply chains) can be more valued by stakeholders than *coercive* adoption of C-TPAT (due to the low level of complexity inherent in the focal firm's upstream supply chains), leading to greater performance outcomes for adopter firms with a high level of complexity.

Signal *observability* refers to how well the signal can be recognized by stakeholders. As noted by Connelly et al. (2011), "*observability* is a necessary but not sufficient characteristic of a signal." A high level of signal *observability* makes it easier for a stakeholder to distinguish firms that have stronger commitment to SCS. The central role of effective signaling pertains to reducing information asymmetry (Connelly et al., 2011; Jiang et al., 2007; Shao et al., 2020). Therefore, the operational performance derived from C-TPAT certification would be contingent upon the extent to which stakeholders encounter difficulty in processing the information about commitment to SCS in adopter firms (*observability*).

Consequently, adopter firms generate greater benefits when stakeholders encounter higher information asymmetry in processing such information (see, e.g., Folta and Janney 2004). Because a complex environment reduces the perception of a firm's commitment to SCS management, the C-TPAT signal improves the *observability* of that firm's commitment to SCS. It is likely that a high level of complexity in the upstream supply chains increases the *observability* of the signal to a greater extent, such that stakeholders could attach more value to the signal of C-TAPT certification. As a result, C-TPAT certification can lead to greater operational performance for firms with a high degree of complexity in upstream supply chains. We separately discuss how *detail, dynamic,* and *spatial* complexity would affect signaling effectiveness below.

3.2.1. Detail complexity

Detail complexity in the upstream supply chains concerns the number of variables in the system (Bozarth et al., 2009). It can result in difficulty for stakeholders in acquiring information about the focal firms' commitment to SCS. Such information asymmetries impose costs on stakeholders in verifying commitment to SCS on the part of focal firms. Bozarth et al. (2009) used the number of suppliers to measure the upstream *detail* complexity. A high level of upstream *detail* complexity indicates a large supply base comprising a large number of suppliers for a buyer firm (e.g., Choi and Hong 2002).

It is possible that a high level of *detail* complexity (e.g., a high number of suppliers) in the upstream supply chain requires more effort by stakeholders in identifying the underlying SCS management status of the adopter firms, thus the signaling *observability* tends to be high. Choi et al. (2001) argued that complexity in the supply base is associated with a buyer firm's extensive interconnectedness with numerous suppliers. Therefore, as the level of *detail* complexity increases, the interconnectedness among adopter firms and stakeholders will become more diversified and difficult to manage, due to the increased number of processes across cultures, regulatory requirements, technical standards, etc. (Yang and Yang 2010). High *detail* complexity (e.g., a large supply base) can motivate importers to adopt C-TPAT from a *rational* perspective, while low *detail* complexity (e.g., a small supply base) can lead to *coercive* adoption of C-TPAT. Therefore, *rational* adoption could help firms clearly signal their commitment to SCS to stakeholders to respond. As a result, the *detail* complexity inherent in the upstream supply chains can lead to greater performance benefits by signaling via certification, particularly for firms having a high rather than a low level of *detail* upstream complexity. This suggests the following hypothesis:

H3. *C-TPAT certification adoption improves operational performance to a greater degree among importers with a greater level of detail complexity than those with a lower level of detail complexity in their upstream supply chains.*

3.2.2. Dynamic complexity

Dynamic complexity is defined as "the unpredictability of a system's response to a given set of inputs, driven in part by the interconnectedness of the many parts that make up the system" (Bozarth et al., 2009). Similarly, a high level of *dynamic* complexity is associated with "situations where cause and effect are subtle, and where the effects over time of interventions are not obvious" (Senge 1990, p.71), and thus where the *observability* of signaling C-TAPT tends to be high. Isik (2010) suggested that variability is associated with the variations of internal and external states (environment). If the types of system elements change rapidly or unexpectedly, the *dynamic* complexity of the system increases. *Dynamic* upstream supply chain complexity affects how stakeholders observe the capabilities of focal firms in managing the turbulence and evolving interconnectedness of various factors in their upstream supply chains. For example, a change in the number of supply chain partners (suppliers) indicates how stable (or unstable) is the interconnectedness between the focal and partnering firms, affecting the ability of stakeholders to identify the underlying commitment to SCS in focal firms. C-TPAT certification, on the other hand, can overcome the drawback of information asymmetry regarding firms' commitment to SCS, whereby a high level of *dynamic* complexity could lead to *rational* adoption while a low level of *dynamic* complexity could result in *coercive* adoption (Arend et al., 2017). As a result, the operational performance created by the signaling benefit is likely to be greater for firms having a high rather than a low level of *dynamic* upstream supply chain complexity. This suggests the following hypothesis:

H4. *C-TPAT certification adoption improves operational performance to a greater degree among importers with a greater level of dynamic complexity than those with a lower level of dynamic complexity in their upstream supply chains.*

3.2.3. Spatial complexity

Spatial complexity captures the degree to which geographical distances or sources of supplies disperse in the system (e.g., Choi and Hong 2002). The more dispersed the sources or distances in the focal firms' upstream supply chains, the higher the uncertainty that the stakeholders will experience in processing information about the underlying commitment to SCS in the focal firms. The dispersion of variables in the focal firms' upstream supply chains may influence how they interact with supply chain partners and provide information about their SCS management to stakeholders. C-TPAT certification may lead to higher signaling *observability* in firms with a high rather than a low level of spatial complexity in upstream supply chains by reducing information asymmetry to a greater extent. For example, the more diverse the sources of annual import goods per supplier, the more information processing, coordination, and monitoring costs may be incurred, due to the different factors among different suppliers, such as exchange rate fluctuations, trade restrictions, and cultural differences. As a result, a high level of *spatial* complexity can increase the *observability* of signaling C-TPAT certification to stakeholders.

Spatial complexity can be manifested in various ways in a firm's upstream supply chain. Consider, for example, that the more dispersed (i.e., further away) the suppliers are from the focal firm, the more effort that the focal firm may need to make to convey SCS dedication to its stakeholders, because the *spatial* complexity inherent in the geographic distance hinders information processing regarding SCS management. Importers having a high rather than a low level of *spatial* complexity may adopt C-TPAT from a *rational* perspective instead of adopting it due to coercive pressure. *Rational* adoption can increase the value of C-TPAT signaling more than *coercive* adoption. This suggests the following hypothesis:

H5. *C-TPAT certification adoption improves operational performance to a greater degree among importers with a greater level of spatial complexity than those with a lower level of spatial complexity in their upstream supply chains.*

4. Method

4.1. Data

We collected data from multiple sources to test the hypotheses, focusing on publicly-listed companies in the U.S. because C-TPAT was developed and driven by this country. Listed companies publicize reliable financial data which can be used for constructing variables of operational performance. There are indeed numerous initiatives regarding SCS management (see, e.g., Table 1 of Hintsa et al., 2009). However, as mentioned above, the C-TPAT program focuses particularly on U.S. border security, aiming at minimizing the risk of importing hazardous cargoes into the extended U.S. supply chain (C-TPAT official website). The CBP provides the advantages to the certified firms of faster clearance and less inspection, or exemption from inspection, which are likely to increase adoption of C-TPAT certification among importer firms if they consider efficiency in customs clearance to be strategically important. Among many other SCS programs, the import-focused SCS nature of the C-TPAT program allows us to investigate how upstream supply chain complexity could affect importer firms' operational outcomes after obtaining C-TPAT certification.

We searched all the announcements pertinent to C-TPAT certification from 2006 to 2014 (a nine-year period). We selected 2006 as the starting year because when we collected data, lading records from the PIERS database could only provide import data since 2005. We need one-year lagged data to construct variables. PIERS (from IHS Markit) is a well-known bill of lading database which consolidates import and export data from U.S. customs trade data through bill of lading searches (https://ihsmarkit.com/index.html). Since there is no publicly available database that consolidates all the records of C-TPAT-certified firms, to identify a preliminary list of certified firms, we thoroughly searched the Factiva/ProQuest/Lexis-Nexis online newspaper and periodicals database, official corporate websites, and corporate 10-K reports using the keywords "customs and trade partnership against terrorism" and "C-TPAT". Through the above steps, we found 194 C-TPAT certification adoption announcements. The use of news retrieval service database (e.g., Factiva, Lexis-Nexis) to construct a sample concerning a specific event (e.g., C-TPAT adoption) is consistent with previous studies (e.g., Arora et al., 2020; Lo et al., 2014). We read the full text of each announcement and excluded unsuitable announcements by taking the following steps. (1) We dropped 29 firms because they had not yet been listed on the U.S. stock exchange when they obtained C-TPAT certification (2) Following the practice in previous studies (e.g., Hendricks et al., 2014) for multiple announcements of C-TPAT certification adoption from the same certified firm, we only included the first announcement in our sample, thus eliminating another 13 announcements. The final sample comprises 152 announcements from 152 different publicly-traded firms with the respective firm names and certification dates.

Relative to other SCS initiatives, the most distinctive benefits provided by the CBP for C-TPAT certified firms include faster lanes for customs clearance, inspection priority, or less/no-inspection privilege, etc. (C-TAPT official website). Due to these advantages granted to importers, we confine our research scope to U.S. importers. The bill of lading records from the PIERS database contains comprehensive information about an importer and its importing records, including the firm address, the names of overseas suppliers, import volumes, lading dates, etc. The CBP should capture manifest data once a U.S importer is engaged in foreign trade via ocean container transport. We classify whether or not a C-TPAT certified firm is an importer by searching for its name (in full and ticker symbol) in all the bill of lading records in *Import Bill of Lading Data* from the PIERS, IHS Markit database (from 2006 to 2014). The data for the import-related variables in the sample used in this study were only available up to 2014 in the IHS database when we collected the data.[1] If a firm's name appears in any bill of lading records during this period, the firm is confirmed as an importer. We double-check the credibility of the matching by looking at whether a firm's address (in the COMPUSTAT database) in our sample is consistent with that (consignee or notify party's address) in the bill of lading record. Among the 152 C-TPAT-certified firms, we found that 101 firms[2] were involved in foreign trade activities via ocean container transport, and we collected their import and supplier data from the bill of lading records accordingly. We then downloaded the financial data of the 101 certified importers from the COMPUSTAT database for further analysis.

Next, we need to match a sample C-TPAT adopter to a C-TPAT non-adopter *importer* firm (control firm). We thus downloaded all the listed firms' company names and financial information with the same four-

Table 1
Distribution of sample firms.

Categories	N	%	Adoption year	N	%
Food and kindred products	7	6.9	2006	15	14.9
Apparel & other textile products	1	1.0	2007	4	4.0
Lumber and wood products	2	2.0	2008	18	17.8
Paper and allied products	11	10.9	2009	5	5.0
Printing and publishing	4	4.0	2010	8	7.9
Chemicals and allied products	10	10.0	2011	5	5.0
Primary metal industries	5	5.0	2012	14	13.9
Fabricated metal products	3	3.0	2013	13	12.9
Industrial machinery & equipment	24	23.8	2014	19	18.8
Electronic & other electric equipment	23	23.0	Total sample firms	101	100
Transportation equipment	3	3.0			
Instruments & related products	1	1.0			
Misc. manufacturing industries	2	2.0			
Other industries	5	5.0			
Sum	101	100			

[1] Adding observations after 2018 could bias the results due to the Covid-19 pandemic, which first occurred in China at the end of 2019 and later spread to the rest of the world. The outbreak of Covid-19 worldwide significantly distorted maritime transport and the metrics we adopted in our study.

[2] There are indeed many more importing firms being C-TPAT certified. However, most of them are privately held firms whose data is not publicly available. Therefore, our sample constraints to the publicly traded firms that we identified to the best of our knowledge. This practice is consistent with previous studies (e.g., Lo et al., 2014). In addition, we conducted an "apple to apple" comparison in later matching procedure (i.e., both sample and control pairs are publicly traded firms).

digit SIC codes as the sample firms during the study period from Standard & Poor's COMPUSTAT database. These firms are candidate control firms that have import records in the PIERS database from 2006 to 2014. We merged the three data sources: the online newspaper and periodicals database, lading record database, and COMPUSTAT financial database to test our hypotheses. Table 1 reports the distribution of the sample importer firms. Fig. 1 provides an overview of the research protocol for this study.

4.2. Matching

To answer the first research question, we examine whether C-TPAT certification adoption is associated with a significant improvement in adopter firms' operational performance. We need to match each sample firm (i.e., a C-TPAT adopter importer) to a control firm (i.e., an importer firm that has not adopted C-TPAT) that has very similar *ex ante* characteristics to the sample firm. Prior research regarding creating sample-quasi control pairs to compare performance outcomes before and after an event has emphasized that only a robust matching can yield comparable sample-control pairs (e.g., Barber and Lyon, 1996; Corbett et al., 2005; Hendricks et al., 2014).

We adopt the coarsened exact matching (CEM, see King et al., 2010, Lacus et al. 2012) method to select a control firm for each sample firm. The CEM approach balances pre-certification covariates between the control and corresponding sample firm. The CEM method is similar to Barber and Lyon (1996) and Corbett et al. (2005) but has several advantages over other matching algorithms because it "generates matching solutions that are better balanced and estimates of the causal quantity of interest that have lower root mean square errors than methods under the older existing class."

Specifically, CEM does not require "determining *ex ante* the size of the matched control sample, then ensuring balance *ex post*." That is, CEM performs exact one-to-one matching by coarsening a set of covariates, ensuring that "strata have at least one treatment and one control unit, then running estimations using the original (but pruned) uncoarsened data" (Aggarwal and Hsu 2014). For instance, using the single nearest neighbor matching method from propensity score matching can lead to imbalanced covariates between sample and control firms. The common practice for achieving balance is to minimize the *caliper* size, which is the difference between sample and control firms' propensity scores. Yet, the number of pairs of sample-control firms used for the subsequent regression will be reduced accordingly (Lacus et al. 2012; Rosenbaum and Rubin 1985). Consequently, the attrition for sample and control observations may bias the results of the regression analysis. To overcome this, the CEM has been applied in numerous management studies as a more stringent matching method (see recent papers using the CEM, e.g., Agrawal and Hsu 2014; Overby and Forman, 2015; Singh et al., 2011). A recent example of CEM application in operations management research is Gray et al. (2015).

We obtained a set of candidate control importer firms from the COMPUSTAT database (see Section 4.1). The CEM method requires matching on categorical dimensions on a 1:1 basis between a sample and a control firm. Following Abadie and Imbens (2006) and Gray et al. (2015), we match a sample C-TPAT certified importer firm to a non-certified importer firm with replacement (a non-certified firm can be matched to several sample firms once the criteria set are met) based on the following criteria: (1) four-digit SIC code; (2) publicly-traded firm; (3) importer firm; (4) employee number category (six discrete buckets): <30, 30–100, 101–250, 251–500, 501–800, and >800; (5) sales (in $ MM, four discrete buckets): <10, 10–20, 21–30, and >30).[3] The selection of these criteria and buckets involves trade-offs between the fraction of the sample (whether a match can be found for a sample) and the stringency of the matching criteria (see Singh et al., 2011, p. 138). "Public" and "importer" criteria are used for controlling firm type, while "four-digit SIC code" ensures sample and control firms are comparable within the same industry, and "employee number" and "sales" are the two metrics accounting for the firm size and marketing capability. The five criteria have been considered comprehensive in matching (e.g., Gray et al., 2015; Lo et al., 2014, Singh et al., 2011) to ensure highly comparable sample-control pairs. We matched a sample firm to a control firm meeting the above criteria by using data from the year when the sample firms implemented C-TPAT certification, which is consistent with recent studies (e.g., Gray et al., 2015; Su et al., 2015). Finally, we matched 101 C-TPAT certified sample firms with 77 control firms. That is, some controls are matched to more than one sample firm. Table 2 gives the characteristics of the sample and matched control firms based on the CEM method. A series of *t*-tests show that sample-control differences are not significant at the 5% level, suggesting that the CEM matching has achieved balance (sample-control pairs are highly similar) without comprising any sample observations to ensure *ex-post* balance.

4.3. Measures

Dependent variable. We measure firms' operational performance using two metrics: return on assets (ROA) and sales growth. ROA is a widely-adopted financial measure to account for the overall efficiency in how a firm's assets can generate profit (e.g., Hendricks and Singhal 2014; Su et al., 2015), calculated by taking the ratio between a firm's operating income (before depreciation) and total assets. We use this metric to examine whether and how adopter firms could experience an overall improvement in operational efficiency through signaling their commitment to SCS via C-TPAT adoption. Sales growth is the annual growth relative to the previous year's sales (e.g., Covin et al., 2006; Lo et al., 2014), which is the ratio between the difference of sales (difference of two consecutive years) and the sales of the earlier year. Sales growth is used as a direct measure to capture how the market and stakeholders react to the signaling of C-TPAT certification.

Independent variables. To test hypotheses 3 to 5, we construct *detail*, *dynamic*, and *spatial* complexity[4] as follows. We use the number of suppliers (in year *t*) to measure *detail* complexity in an adopter firm's upstream supply chain. The greater the number of suppliers in an importer firm's upstream supply chain, the greater the level of *detail* complexity will be (Choi and Hong, 2002). *Dynamic* complexity is measured by the change rate in the number of suppliers between two consecutive years (*t*-1 and *t*). This variable helps capture how the variability of complexity in the upstream supply chain affects the performance value of C-TPAT certification through signaling SCS commitment. In this study, *spatial* complexity in the upstream supply chain reflects diversity (dispersion) in terms of suppliers per unit of import goods (year *t*). That is, the more diverse the supplier origins per unit of import goods, the higher the level of upstream complexity. Consider, for example, that firm A has only one supplier providing it with 60 units of goods annually, while firm B imports from three different suppliers with an equal total annual import volume of 20 units from each supplier. Although the total annual import volumes are the same for both firms, the levels of complexity in dealing with SCS management for suppliers in the two scenarios are different. The complexity in dealing with SCS issues in firm B is higher than that in firm A because SCS decision-making and coordination are more dispersed in firm B than in firm A. Hence, we use the well-established inverse of concentration index (*Herfindahl-Hirschman Index*, *HHI*, see Derfus et al., 2008) to measure *spatial* complexity (the degree to which suppliers per unit of

[3] Our results were robust if we divide the sales into more buckets (e.g, five) in the matching.

[4] In the context of this study, since C-TPAT certification mainly addresses security at the *import* side across U.S. borders concerning the upstream activities in a firm's global supply chain, we confine our study scope to the *upstream* complexity of supply chains.

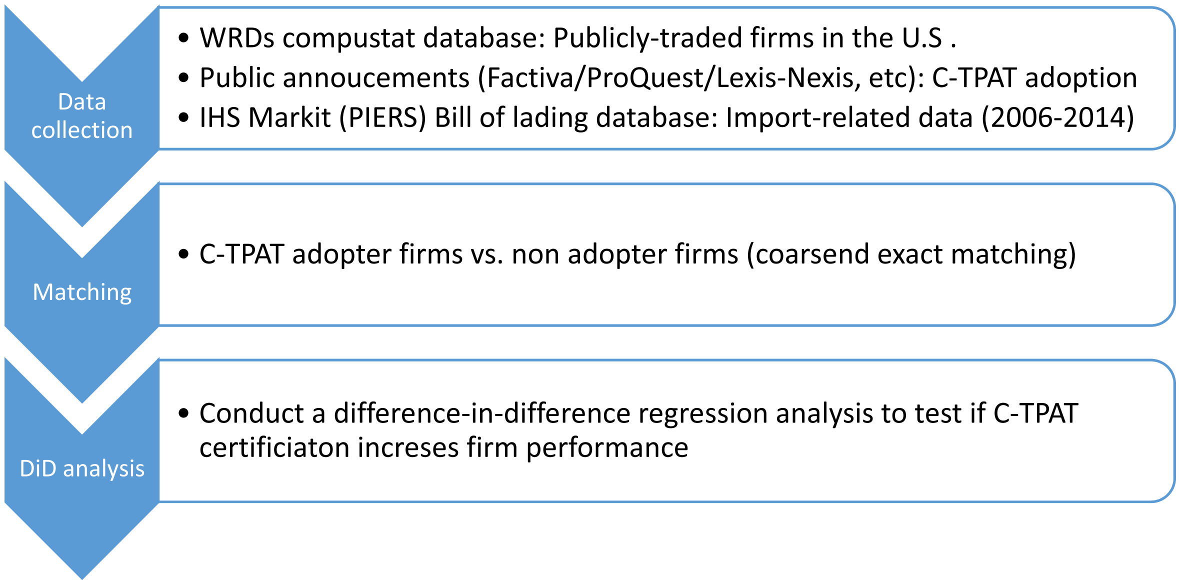

Fig. 1. Research protocol.

Table 2
Matching criteria and results of CEM.

	Certified		Matched	
	Mean	S.D.	Mean	S.D.
Employee number	314.1	287.2	334.6	280.4
Sales	54.4	24.8	53.9	23.5
Four-digit SIC code same?	Yes			
Publicly traded firm?	Yes			
Importer firm?	Yes			
N	101		77	

Note. Some firms are matched with more than one certified firms (matching with replacement, see Section 4.2).

import goods are dispersed). In this study, HHI_k is defined as the concentration of suppliers per unit of import goods. $HHI_k = \sum_{s=1}^{n_s} r_{k_s}^2$, where r_{k_s} is the ratio between annual import volume from supplier s and the total annual import volume from all suppliers in firm k. n_s is the total number of suppliers of firm k. Accordingly, *spatial* complexity in firm k is the inverse of the concentration index, i.e., 1-HHI_k.

Control variables. We control for the following variables that may affect the importer firms' performance. *Firm size* is the natural logarithm value of the total number of employees. *Market value* is measured by Tobin's Q ratio (e.g., Chung and Pruitt 1994). Consistent with previous econometric analyses (e.g., Baum and Wally 2003; Su et al., 2015), we need to control for the potential effects of current firm performance (i.e., the dependent variable of year *t*) in predicting future dependent variables (year *t*+1 and *t*+2). Hence, we use DV (*t*), that is, the dependent variable constructed in year *t*, to control for the possible portion of heterogeneity resulting from past performance (e.g., Greene, 2003; Wooldridge 2009). The *import volume* (natural logarithm of annually imported container volume) and the *volume change rate* (the difference between two consecutive years' import volume over the earlier year's import volume) would also affect firm performance. We also control for the two variables in the regression models.

4.4. Econometric modeling: difference-in-difference analysis

Our data is longitudinal across multiple subjects (i.e., firms), so we consider partitioning variance between and within subjects (see Fitzmaurice et al., 2012). To test H1 and H2, we use a difference-in-differences (DID) analysis (Wooldridge 2009) to address the potential variability existing in between-subject differences (e.g., the persistent mean-level difference in ROA) and within-subject differences over repeated measurements (e.g., variation in a firm's yearly ROA from its mean ROA for the study horizon) (Fitzmaurice et al., 2012). The availability of both *ex ante* and *ex post* C-TPAT certification data allows us to remove all stable sources of between-firm variability, leaving only variability within firms over time. It is important to remove the between-firm variability from the analysis because it can affect outcome variables (e.g., Jacobson 1990). The DID analysis has been widely used in the literature to examine the impact of an event on performance during *ex ante* and *ex post* periods (e.g., Aggarwal and Hsu 2014; Gray et al., 2015; Overby and Forman, 2015).

To understand the hypothesized effects of C-TPAT certification on importer firms' operational performance, we use a DID analysis to detect whether there is a statistically significant difference between (i) the difference in outcome variables between certified importer firms and their matched control firms in the pre-certification period (*ex ante* difference) and (ii) the difference in outcome variables between certified importer firms and their matched control firms in the post-certification period (*ex post* difference). That is, the following OLS model specifies a DID regression.

$$Y = \alpha_0 + \gamma_0 \, Post + \alpha_1 \, Certified + \gamma_1 \, Post \times Certified + e$$

Where Y is ROA or sales growth, *Certified* is a binary variable, taking a value of 1 for all certified importer firms and 0 for all control firms. Similarly, *Post* takes a value of 1 if the outcome variable lies in the post-certification period for both certified and non-certified control firms, 0 otherwise ($Post = 0$ if the outcome variable lies in the pre-certification period for both certified and non-certified firms). e is an error term. Intuitively, we expect a significant and positive γ_1 to indicate that the difference in the post-certification period between the certified firms ($Certified = 1$ and $Post = 1$) and their matched control firms ($Certified = 0$ and $Post = 1$) is greater than the difference in the pre-certification period between the certified firms ($Certified = 1$ and $Post = 0$) and their matched control firms ($Certified = 0$, $Post = 0$). No control variables are included in this step because the "(sample firms) are matched" (Gray et al., 2015). Table 3 gives the results of the DID OLS regressions. As can be seen, in the ROA model of year *t*+1, the key variable of *Certified* × *Post* is statistically significant at the 1% level, suggesting that C-TPAT certification positively affects importer firms' profitability (ROA). The result of the ROA model in year *t*+2 also suggests that certification leads

Table 3
Descriptive Statistics for regression analysis.

Variable	Mean	Std. Dev.
ROA	0.15	0.03
Sales growth	0.16	0.03
Firm size	3.90	0.50
Market value	1.92	1.03
ROA *t*	0.14	0.04
Sales growth *t*	0.13	0.06
Import volume	3.85	1.40
Volume change rate	0.87	0.35
Supplier number	3.83	1.39
Supplier change rate	0.15	0.17
Spatial	0.34	0.06

Note. These variables may be time varying; we report them during the year t+1 (year t is the C-TPAT certification year) unless otherwise specified.

to a significant increase in ROA ($p < 0.01$). Moreover, the two key variables of *Certified* × *Post* in the sales growth models of years t+1 and t+2 are also statistically significant at 1%. Collectively, the results show that C-TPAT certification helps importer firms improve profitability and sales growth vis-à-vis matched non-adopters. Therefore, H1 and H2 are supported (see Table 4).

4.5. *Upstream supply chain complexity*

To test H3 to H5, we examine the effect of upstream supply chain complexity on firms' post-certification operational performance. Specifically, we test how *detail*, *dynamic*, and *spatial* complexity, measured by the number of suppliers, the change rate of the number of suppliers, and the source diversity of per-unit import goods, respectively, affect the operational performance in C-TPAT-certified importer firms. Here, because our analysis only involves certified firms, but is no longer a matched sample, we include control variables (see Gray et al., 2015, p.8) to account for their potential effects on operational performance.

We first use OLS regression with residual analysis to find out whether heteroscedasticity exists. Using a *Breusch-Pagan* and a *White* test (Kosowski et al., 2007, White, 1980), we confirm that the models are subject to heteroscedasticity problem ($p = 0.000$). One approach to address this problem is to use the panel-fixed effects with robust standard errors approach (e.g., Stock and Watson 2008). However, in our study, the independent variables of *detail*, *dynamic*, and *spatial* complexity do not necessarily update in the study period such that panel-fixed effect models could reduce multiple observations. Following Su et al. (2015), we use the panel generalized least squares (GLS) method to account for heteroscedasticity, which has been widely applied in management studies (e.g., Gedajlovic and Shapiro 2002; Zhang and Rajagopalan, 2010). We specify the following model to investigate the effect of supply chain complexity (*detail*, *dynamic*, and *spatial*) on firms' operating performance.

Table 4
Difference-in-difference analysis.

	Year (t +1)		Year (t +2)	
Variable	ROA	Sales growth	ROA	Sales growth
Certified	0.003	0.002	0.001	−0.001
	(0.004)	(0.004)	(0.005)	(0.003)
Post	0.015***	0.006	0.011**	0.020***
	(0.005)	(0.004)	(0.005)	(0.004)
Post × *Certified*	0.051***	0.068***	0.082***	0.051***
	(0.017)	(0.016)	(0.017)	(0.016)
Constant	0.106***	0.083***	0.105***	0.090***
	(0.003)	(0.003)	(0.003)	(0.003)
R-squared	0.036	0.028	0.033	0.027

***$p < 0.01$.
**$p < 0.05$.

Table 5
The effect of upstream supply chain complexity.

	Model 1	Model 2	Model 3	Model 4
Variable	ROA (t+1)	Sales growth (t+1)	ROA (t+2)	Sales growth (t+2)
Firm size	−0.000	−0.002***	0.001	0.001
	(0.001)	(0.001)	(0.002)	(0.002)
Market value	0.000	−0.000	0.002**	0.002**
	(0.000)	(0.000)	(0.001)	(0.001)
DV (t)	0.109***	−0.0001	0.067	−0.004
	(0.014)	(0.002)	(0.043)	(0.003)
Import volume	0.003**	0.007***	0.015***	0.013***
	(0.002)	(0.002)	(0.004)	(0.004)
Volume change rate	0.001	0.000	−0.002	−0.002
	(0.001)	(0.002)	(0.003)	(0.003)
Supplier number (H3)	0.010***	0.018***	0.018***	0.022***
	(0.003)	(0.004)	(0.005)	(0.004)
Supplier change rate (H4)	0.004***	0.006***	0.010**	0.011***
	(0.002)	(0.002)	(0.005)	(0.005)
Spatial (H5)	0.195***	0.128***	0.080**	0.079**
	(0.044)	(0.041)	(0.032)	(0.034)
Constant	−0.062***	0.063***	0.064***	0.081***
	(0.017)	(0.012)	(0.018)	(0.019)
Industry dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Wald's Chi2	20873.44***	11156.29***	2986.63***	2959.70***

Standard errors in parentheses. Heteroskedastic Panel structure is used.
All tests are two-tailed.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

(VIF) in all models and find the maximum VIF is 3.37 (<10), suggesting that there is no multicollinearity problem (Cohen et al., 2013). The

$$DV_{t+k} = \alpha_0 + \alpha_i I_i + \alpha_i Y_i + \alpha_1 \, Market\ value_k + \alpha_2 \, Firm\ size_k + \alpha_3 \, DV_{(t)} + \alpha_4 \, Import\ volume_t + \alpha_5 \, Volume\ change\ rate_t + \alpha_6 \, Supplier\ number_t + \alpha_7 \, Supplier\ change\ rate_t + \alpha_8 \, Diversity_t + e$$

where I_i and Y_i are industry and year dummies, respectively, $k = 1$ or 2 for the following two years' operational performance since the certification adoption year (year t). $DV_{(t)}$ refers to the previous firm performance metric-ROA or sales growth and e is the random error term.

Table 5 gives the results of the control variables and independent variables of the *detail*, *dynamic*, and *spatial* complexity on the operating performance of sample firms. We check the variance inflation factor (VIF) in all models and find the maximum VIF is 3.37 (<10), suggesting that there is no multicollinearity problem (Cohen et al., 2013). The control variables of *import volume* are positive and significant in all models. It appears that a higher level of import volume in a firm is associated with a higher operating performance after certification, which can be attributed to the tangible and direct advantages offered by the CBP in the customs clearance process that help firms translate such advantages into monetary savings. *Detail* complexity, as measured by supplier number, is highly significant in all models. For instance, in model 1, $p < 0.01$, $\beta = 0.010$, it suggests that an increase in one unit of *detail* complexity is significantly associated with a 0.01 increase in ROA across sample firms on average. Therefore, H3 is supported. *Dynamic* complexity, measured by the change rate of supplier number, is also a significant predictor of firms' operating performance. For example, on average, firms can expect a 0.6% increase in sales in the first year after certification (in column 2, $p < 0.01$). This supports H4. Also, as measured by the source diversity of per-unit import goods (the inverse *HHI* of the volume of import goods from different suppliers), *spatial* complexity significantly increases the operating performance in C-TPAT certified firms. For example, in Model 4, on average, a unit increase in *spatial* complexity significantly leads to a 0.079 increase of sales ($p < 0.05$). Thus, H5 is supported.

4.6. Robustness checks

Our model has several forms of built-in robustness, since we used two performance metrics (ROA and sales growths), and we showed the results of *ex post* certification performance lasting two years (t+1 and t+2). However, we need to check if the lagged variables are correlated with the error terms, leading to potential endogeneity issues. More importantly, there is a concern that other endogeneities arising from the reverse causation may threaten the hypothesized relationship between C-TPAT certification and operational performance. That is, adopter firms' operational performance can also affect the adoption decision made by the managers. In addition, some unobservable firm-fixed variables such as organizational culture could contribute to the dependent variables (Su et al., 2015). Wooldridge (2010) suggested that when the estimation is subject to heteroscedasticity, a two-step GMM is efficient and robust to mitigate endogeneity in model estimation. To reasonably address the above concerns, we use lagged dependent variables (in year t-1) as the instrumental variables in the system generalized method of moments (GMM) model (Blundell and Bond 1998).

To do this, we first need to confirm the validity of constructing instrument variables by using the lagged dependent variables. We use the *Sargan* test to check if the instrumental variables are correlated with the error terms (Wooldridge 2010). In Table 6, the *Sargan* test of overid p values are all greater than 0.10, failing to reject the null hypothesis that the instrumented variables are uncorrelated with the error term. The instrumented variables are exogenous and thus are valid to account for endogeneity in the estimation. In addition, we find that all the p values of the first-order autocorrelation (AR1) are statistically significant (<0.01), meaning that the residuals in difference are correlated. Relying on this inefficient first-order GMM estimator, the second-order autocorrelation (AR 2) tests show that all p values are larger than 0.10, suggesting the null hypothesis that there is no serial correlation in the idiosyncratic disturbances (those apart from the fixed effects) cannot be rejected. Collectively, we confirm that the instrumented variables are effective in the specified GMM models and that the GMM models are not misspecified. The results in Table 6 are similar to those in Table 5, suggesting that the effects of supply chain complexity on the operational performance are very robust.

Table 6
Robustness checks.

	Model 1	Model 2	Model 3	Model 4
Variable	ROA (t+1)	Sales growth (t+1)	ROA (t+2)	Sales growth (t+2)
Firm size	−0.002***	−0.002***	0.001	0.001
	(0.001)	(0.001)	(0.002)	(0.002)
Market value	0.000	0.000	0.002**	0.002**
	(0.000)	(0.000)	(0.001)	(0.001)
DV_instrumented	0.109***	0.004***	0.055***	0.013
	(0.014)	(0.002)	(0.023)	(0.009)
Import volume	0.005***	0.006***	0.015***	0.014***
	(0.002)	(0.002)	(0.006)	(0.007)
Volume change rate	0.000	0.000	−0.002	−0.001
	(0.001)	(0.001)	(0.002)	(0.001)
Supplier number (H3)	0.009***	0.018***	0.018***	0.017***
	(0.003)	(0.005)	(0.005)	(0.006)
Supplier change rate (H4)	0.004***	0.005***	0.009***	0.009***
	(0.002)	(0.002)	(0.004)	(0.003)
Spatial (H5)	0.190***	0.126***	0.072**	0.080***
	(0.044)	(0.040)	(0.031)	(0.032)
Constant	−0.060***	0.061***	0.063***	0.080***
	(0.017)	(0.011)	(0.017)	(0.018)
Industry dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Wald's Chi2	20566.32***	11053.36***	2887.53***	2313.34***
AR (1) p value	0.00	0.00	0.00	0.00
AR (2) p value	0.78	0.69	0.38	0.47
Sargan test of overid (p)	0.33	0.37	0.41	0.39

Standard errors in parentheses. All tests are two-tailed.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

5. Discussion

The urgent need to secure the global supply chain, in particular, to ensure import-side security in upstream supply chains, has pressurized government agencies (e.g., U.S CBP) and supply chain partners (e.g., importing firms) to actively participate in security enhancement programs such as the C-TPAT. Although extant research has examined the SCS initiatives and firm performance (e.g., Whipple et al., 2009; Yang and Wei 2013), these studies used perceptual constructs on variables suffering from sample selection bias. They provided inconclusive findings on the performance benefits of C-TPAT certification. More importantly, prior studies have not differentiated C-TPAT certification from other *process* management standards where second-order performance outcomes may be attributed to non-operational factors such as signaling commitment to SCS management via a standard certification. To this end, we investigate the benefits of C-TPAT certification from a signaling theory perspective. The data in this study come from multiple archival data sources (e.g., news announcements, importing records, and financial performance). We show that C-TPAT adoption can improve the *observability* and *credibility* of firms' commitment to SCS for stakeholders, increasing firms' operational performance. Also, since information asymmetry can be affected by the levels of the upstream supply chain complexity, we examine whether and how the signaling of commitment to SCS through the adoption of C-TPAT certification is apt to vary across *detail*, *dynamic*, and *spatial* complexity in the importer firms' upstream supply chains. Collectively, the findings of this study complement the research stream on SCS and supply chain complexity by revealing that importer firms can leverage C-TPAT certification as a signal to convey commitment to SCS to stakeholders and the significant role of upstream supply chain complexity on the operational performance outcomes.

5.1. Implications for theory

This paper offers several important and novel contributions to theory in SCS management studies. Numerous studies have investigated management standard certifications such as ISO series certifications (e.g., ISO 9001 for quality management and ISO 14001 for environment management). These management standards are largely concerned with promoting improvements in adopter firms' internal process management (see Linderman et al., 2010; Schroeder et al., 2008), meaning "an organized group of related activities that work together to create a result of value to the customer" (Hammer 2002, p.26). Effective *process* management is expected to create knowledge (Linderman et al., 2010). However, direct or tangible benefits are not guaranteed by adopting such standards. This study uses a signaling theoretical perspective to examine the potential benefits that adopter firms can obtain from

C-TPAT certification, which is different in some ways from the conventional process management standards.

We use a robust method (i.e., CEM) to match sample firms with properly selected control firms and investigate the hypothesized performance benefits from C-TPAT certification in adopter importer firms. We argue that C-TPAT serves as the signal that adopter importers distinguish themselves from firms with low commitment to SCS by reducing the information asymmetry imposed on stakeholders. From a signaling-performance relationship point of view, we demonstrate that adopting C-TPAT certification is an effective signaling tool to convey commitment to SCS to stakeholders, increasing operational performance (ROA and sales growth) in adopter firms.

The second research question in this study deals with the upstream supply chain contingencies that may affect the signaling benefits. Specifically, the signaling benefit of C-TPAT certification appears to be heterogeneous across importer firms that vary in upstream supply chain complexity. We find that the benefit depends on the level of upstream supply chain complexity, which includes *detail*, *dynamic*, and *spatia*l complexity. We first argue that C-TPAT certification is more advantageous for firms with a high level of upstream complexity because they tend to adopt C-TPAT from a rational perspective (they are motivated by the advantages of fast lane/less inspection or exemption from inspection in the customs clearance process), while others may be coerced to adopt certification due to legitimacy reasons. The distinct motivations of firms that vary in their levels of upstream complexity can lead to a higher increase in marginal revenue for rational adoption (firms with high upstream complexity) than coercive adoption (firms with low upstream complexity).

On the other hand, a high level of complexity may lead to a high signal *observability* of C-TPAT certification. C-TPAT certification can better signal adopter firms' commitment to SCS as perceived by stakeholders when the upstream complexity in the focal firms is higher than when it is low. Specifically, the level of *detail*, *dynamic*, and *spatial* complexity reflects the extent to which the upstream supply chain is complex in terms of the number of suppliers, the unpredictability of supplier change, and the dispersion among sources of import goods divided among suppliers, respectively, which provides a holistic view of upstream supply chain complexity characterizing importer firms' SCS management. As a result, our research contributes to the SCS management literature by highlighting the effect of upstream supply chain contingencies on SCS management. In particular, signaling SCS commitment via standard certification should not be considered as "one size fits all" for SCS, but taking supply chain contingencies into account could help firms better interpret and utilize the benefits.

This study also contributes to the literature on management standards. Research on management standards (e.g., ISO 9001 or ISO 14001) gives mixed results about the financial performance benefits generated from implementing these standards (see, e.g., Corbett et al., 2005, Singh et al., 2011). Researchers argue that certifications could serve as resources for adopter firms to generate competitive advantages from a RBV perspective (see, e.g., Nair and Prajogo 2009; Prajogo et al. 2012). That is, adopter firms could take advantage of management standards as heterogeneous and immobile resources to generate sustained competitive advantages vis-à-vis rivals who are not able to access the resources (Barney 1991). However, the use of RBV for firms in the study of management practices is controversial in the operations management literature (see Bromiley and Rau 2016; Hit et al. 2016; Ketokivi 2016). For example, the assumption that such resources (certifications) are difficult to imitate may be problematic (e.g., Su et al., 2015). In promoting these standard certifications, a certain degree of isomorphism (Deephouse 1996) across organizations is encouraged, leading to homogeneity (instead of heterogeneity) among organizations in the diffusion of management standards. In this study, the CBP claims that "from its inception in November 2001, C-TPAT continued to grow." That is, management standards may not follow the tenets of the *RBV of the firm,* which argue that resources are rare, valuable, inimitable, and non-substitutable in nature. As a result, RBV may not be appropriately used to argue that certification can create heterogeneity between firms, which is the source of competitive advantage and high performance. By contrast, we conceptually and empirically show that performance gains can be obtained from management standards through a signaling mechanism. While C-TAPT certification is imitable and substitutable, the signaling perspective explains how adopter firms can generate competitive advantages from the adoption of the standard. Specifically, C-TPAT certification signals a firm's commitment to SCS to stakeholders. Because information asymmetry exists between focal firms and stakeholders, management standard adoption helps to reduce such information asymmetry and bring performance gains for focal firms. In particular, when tangible and direct benefits are offered by the certifying body, adopter firms can benefit from adopting certification by signaling to their stakeholders that they could enjoy the advantage of such benefits, enabling them to increase operational performance. Therefore, it is noticeable that management standards like C-TPAT differ from conventional process-based management standards where no direct operational advantages are offered by the certifying body. From the signaling theory perspective, we demonstrate that C-TPAT certification leads to performance gains in adopter firms.

Our paper also contributes new knowledge to the recent development on global SCS research (Jażdżewska-Gutta et al., 2020; Su et al., 2021) in that we show the effectiveness of the signaling mechanism which benefits security management adopter firms in terms of profitability and sales growth. In addition, the signaling benefits can be amplified along with the increased upstream supply chain complexity. To this end, we extend the use of signaling theory to SCM context by explicating the contingencies that facilitate firms to reap the performance value of SCS certification.

5.2. Implications for practice

The results of this study also offer managerial implications for practitioners and policy makers. We use a rigorous matching and econometric analysis to study whether and how C-TPAT certification leads to improvement in operational performance in adopter firms, showing that adopter importer firms can expect improvement in operational performance compared with matched non-adopter firms. This alleviates the concern in the literature that C-TPAT may not be able to deliver a positive return on investment but may burden firms with a high investment cost (e.g., Rice and Caniato 2003). As a result, potential adopters can expect an increase in profitability, in particular importer firms with high levels of upstream complexity. From a policy-making standpoint, the CBP may highlight the beneficial effects of C-TPAT certification on importer firms' profitability in promoting this program. Promotion targeting importer firms with a greater level of complexity in their supplier portfolio (e.g., higher supplier number, greater change in supplier number, and greater source diversity of import goods) should be accorded higher priority. The performance value of C-TPAT certification should be cogently communicated to the target audience (e.g., importer firms) as well.

5.3. Limitations and future research directions

This study is also subject to several limitations that future research could address. First, we study a sample of publicly-traded U.S. importer firms. The implications of this study may not be generalizable to other contexts, such as private firms whose financial data is not publicly available and whose operating environments differ significantly from those of public firms. A survey study can be conducted to understand the operational performance change due to certification in private firms. Second, the complexity of supply chain in this study is restricted to the upstream supply chain because C-TPAT certification mainly focuses on importing activities where smooth communications and coordination with suppliers in packaging, containerization, documentation, insurance, storage, and import/export regulations are needed. However, it would also be interesting to study how downstream complexity may affect the performance benefits of C-TPAT certification. As noted by Bozarth et al. (2009), downstream complexity can be constructed by "the number of customers, the heterogeneity of customer needs, the average length of the product life cycle, and the variability of demand." Future research is encouraged to study how such variables may also influence how adopter firms convey commitment to SCS through signaling C-TPAT certification. In addition, echoing the recent call-for-research in understanding security breaks in retailing context (Su et al., 2021), we suggest future studies paying more attention to aligning upstream SCS mitigation strategies with downstream distribution strategies in dealing with SCS breaches holistically.

6. Conclusions

This study investigated the extent to which SCS certification can influence firms' operational performance from the signaling theoretical perspective. We empirically demonstrated that adopting C-TPAT certification, initiated by the U.S. Customs and Border Protection (CBP), improves financial performance in adopter firms and the level of upstream supply chain complexity (*detail*, *dynamic*, and *spatial* complexity) enhances the operational performance derived from the C-TPAT certification. More broadly, this study sheds light on the performance value of a management standard that is attributed to the non-process mechanism (not due to *process* improvements) enabled by the signaling effectiveness incorporating the upstream supply chain complexities.

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