

# Trade Credit Insurance: Operational Value and Contract Choice

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Trade credit insurance (TCI) is a risk management tool commonly used by suppliers to guarantee against payment default by credit buyers. TCI contracts can be either *cancelable* (the insurer has the discretion to cancel this guarantee during the insured period) or *non-cancelable* (the terms cannot be renegotiated within the insured period). This paper identifies two roles of TCI: The (cash flow) *smoothing* role (smoothing the supplier's cash flows), and the *monitoring* role (tracking the buyer's *continued* creditworthiness after contracting, which enables the supplier to make efficient operational decisions regarding whether to ship goods to the credit buyer). We further explore which contracts better facilitate these two roles of TCI by modeling the strategic interaction between the insurer and the supplier. Non-cancelable contracts rely on the deductible to implement both roles, which may result in a conflict: A high deductible inhibits the smoothing role, while a low deductible weakens the monitoring role. Under cancelable contracts, the insurer's cancellation action ensures that the information acquired is reflected in the supplier's shipping decision. Thus, the insurer has adequate incentives to perform his monitoring function without resorting to a high deductible. Despite this advantage, we find that the insurer may exercise the cancellation option too aggressively; this thereby restores a preference for non-cancelable contracts, especially when the supplier's outside option is unattractive and the insurer's monitoring cost is low. Non-cancelable contracts are also relatively more attractive when the acquired information is verifiable than when it is unverifiable.

*Key words:* insurance, risk management, trade credit, moral hazard, operations–finance interface

*History:* First draft: February 2016; current version: December 2019

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## 1. Introduction

Trade credit arises when a supplier allows a buyer to delay payment for goods or services already delivered. There is a large body of work that suggests that trade credit greatly facilitates trade (Giannetti et al. 2011). However, a supplier that grants credit also runs the risk of payment default – that is, the buyer may substantially delay payment or fail to pay altogether. Such defaults can create severe financial difficulties for the suppliers, especially among small and medium-sized

enterprises (SMEs). In fact, an estimated one in four SME insolvencies in the European Union is due to payment defaults (Milne 2010).

To protect themselves against such negative events, suppliers often purchase trade credit insurance (TCI), which allows the insured party to recover losses arising from the buyer defaulting. In deciding whether to ship goods to a credit buyer, a supplier balances the benefit from the trading transaction against the downside associated with payment default. TCI helps tip the balance in favor of shipping, and thereby enhances trade. TCI can be used to insure a single supplier-buyer transaction, which this paper focuses on for simplicity, or the entire trade between a supplier and a predetermined set of buyers for a fixed duration (typically a year). TCI first became popular in Europe; however, it now has a substantial global footprint. TCI is offered by specialized trade credit insurers such as Euler Hermes and Atradius, general insurers such as Swiss Re and AIG, and national export-import banks (Jones 2010). As of 2016, TCI covered more than €2.3 trillion of exposure globally (International Credit Insurance and Surety Association 2017).

TCI resembles traditional insurance in certain respects and is distinct in others. Specifically, it resembles other forms of insurance in that it is meant to guarantee payment to the insured party (the supplier) under certain conditions. However, distinct from contracts used in other insurance settings, the TCI contract often allows the insurer to cancel coverage – in whole or in part – at any time prior to the shipment of goods. This is achieved by first determining the *credit limit* (coverage) for a specified time period, but then within this very time period, allowing the insurer to withdraw or amend these limits if the insurer determines that there has been a significant change in the credit risk (Jones 2010, Association of British Insurers 2016).<sup>1</sup>

It is fairly common for insurers to exercise the flexibility to cancel coverage when they believe that the risk of payment default has deteriorated. In just the first few months of 2009, canceled TCI credit lines amounted to €75 billion (International Financial Consulting 2012). Once TCI is withdrawn for their buyers, suppliers tend to stop shipping on credit. This dynamic naturally undermines both parties' abilities to trade (Kollewe 2009). It is estimated that 5% to 9% of the total drop in world exports during the recent financial crisis can be attributed to the withdrawal of trade credit insurance (van der Veer 2015). An unwarranted cancelation adversely affects the *efficiency of the shipping decision* and leads to economic losses.<sup>2</sup> Thus, exercise of the cancelation

<sup>1</sup> The *credit limit* is the amount that the insurer will reimburse the insured in case of payment default, minus any deductible (Association of British Insurers 2016). Note that the credit limits in cancelable TCI may be revised at a *discretionary* time; this is distinct from the *periodic* decision of whether or not to renew a policy and/or revise its terms, or coverage cancelation based on a set of pre-determined conditions (e.g., the claimholders misrepresenting themselves on their applications), which are commonplace in insurance settings.

<sup>2</sup> We refer to a shipping decision as being *efficient* if it is consistent with the decision when the supplier and the insurer acts as a single decision-maker.

option is often contentious owing to its significant operational and financial implications. In the words of Bill Grimsey, chief executive of Focus DIY, the UK homeware retailer, credit insurers are “fair-weather friends who don’t go into enough detail, make unilateral decisions at short notice and jeopardize the futures of businesses” (Stacey 2009).

An alternate approach to contracting for credit insurance, and a response to the concerns about cancelation, is embodied in non-cancelable coverage. As the name suggests, the credit limits in non-cancelable coverage cannot be altered within a specified time period (AIG 2013, Association of British Insurers 2016). Given the high stakes, the relative merits of the two contracting approaches are being hotly debated in the practitioner community (Aitken 2013).

Motivated by the above discussion, we investigate the following questions in this paper: 1) What roles does TCI play in a supply chain? 2) What are the relative merits of cancelable versus non-cancelable contracts, and what principles should guide the choice of contract form?

To answer these questions, we develop a game-theoretic model that captures the strategic interactions between the supplier and the insurer for a single transaction. A risky buyer places a credit order with the supplier, who incurs financing costs when facing a cash shortfall. The supplier buys TCI from the insurer to protect itself against the risk of the payment default. Thereafter, the insurer can exert costly yet unverifiable monitoring effort to obtain updated information about the buyer’s default risk. This salient feature of the model captures the fact that TCI covers the buyer’s *default risk*, which is not internal to the insured firm (supplier) and is evolving. In practice, the insurer often has a superior capability to gather and analyze information about the buyer’s default risk from a variety of channels, such as closely monitoring publicly available information sources (e.g., financial statements), and non-public sources such as site visits, and tracking the buying firm’s payment history (Jones 2010, Amiti and Weinstein 2011, Association of British Insurers 2016, Euler Hermes 2018). The obtained market intelligence, which may reflect worsening political or geographical risk (Freely 2012), or the buyer’s deteriorating financial situation (Birchall 2008), has been proven to be powerful in predicting payment default (Kallberg and Udell 2003, Cascino et al. 2014). Based on the *updated* assessment of the buyer’s risk provided by the insurer, the supplier may revisit her decision to ship the order.

By comparing the centralized benchmark with the scenario in which insurance is not available, we quantify the two roles that TCI fulfills. First, on the financial side, TCI smoothes the supplier’s cash flow across different possible realizations of buyer’s risk, and thereby mitigates the adverse financial effect of payment default. We refer to this as the (cash flow) *smoothing role* of TCI. Second, and different from other insurance settings, TCI is also an information service that facilitates operational decisions. Specifically, by gaining access to the information that the insurer may have gathered regarding the buyer’s evolving creditworthiness, the supplier can make more

efficient operational (shipping) decisions. By steering the shipping decision towards efficiency, this *monitoring role* of TCI creates operational value that goes beyond pure financial considerations. Fulfilling the monitoring role of TCI requires that the insurer has the incentive to obtain updated information, and that the supplier makes efficient shipping decisions based on the update. These two incentive issues are crucial determinants of the optimal form of TCI contracts.

We mainly focus on two forms of TCI contracts: non-cancelable and cancelable contracts. Under the non-cancelable contract, which is similar to a standard contract in other insurance settings, the credit payment from the buyer, minus a deductible, is guaranteed by the insurer in exchange for a premium. A cancelable contract, however, gives the insurer an option to cancel coverage before the order is shipped. We find that a non-cancelable contract with a deductible is limited in its ability to fulfill both the smoothing and monitoring roles of TCI. On the one hand, a low deductible does not deter the supplier from shipping even when the buyer's creditworthiness deteriorates. Such an inefficient reaction to the updated information reduces the insurer's incentive to monitor, thereby weakening the monitoring role of TCI. On the other hand, a high deductible has two possible drawbacks: first, it may expose the supplier to higher financing costs, compromising the smoothing role; second, it may also discourage monitoring by reducing the insurer's exposure to the credit loss. As such, non-cancelable contracts are able to recover the full value of TCI only when the supplier is financially well-off and the insurer's monitoring cost is low.

By contrast, with cancelable contracts, the insurer's option to cancel coverage makes it possible to incorporate his acquired information about the buyer's risk to appropriately influence the supplier's shipping decision. In particular, compared to non-cancelable contracts, the insurer is now more motivated to invest in costly monitoring because upon learning that the buyer is overly risky, he can deter the supplier from shipping by exercising the option to cancel, without resorting to a high deductible. These dynamics explain why cancelable insurance contracts have long prevailed in the TCI industry.

Despite this advantage, we find that because the insurer does not benefit directly from the trade after the insurance contract is signed, the insurer may *over-cancel*, i.e., cancel the supplier's coverage even when it is efficient to ship. This incentive hurts the performance of the cancelable contract when the supplier's outside option is unattractive (e.g., during an economic downturn), and the insurer's monitoring costs are low (which may result from superior information systems and/or analytical capabilities). Under these circumstances, the supplier may prefer non-cancelable contracts, which serve as a commitment by the insurer to provide coverage. This preference for non-cancelable contracts offers a possible explanation for the greater enthusiasm for non-cancelable coverage following the Great Recession of 2008. We also find that contracts that combine the advantages of cancelable and non-cancelable features can further enhance the value of TCI.

Finally, compared to the case when information is verifiable, when the information collected by the insurer is *unverifiable* and is subject to strategic manipulation, cancelable contracts in general become more attractive relative to non-cancelable contracts. This is because the insurer's cancellation action serves as a credible signal of the (unverifiable) information. The result also suggests that non-cancelable contracts will become relatively more attractive as the acquired information can be credibly communicated by other channels (e.g., IT integration).

The contribution of the paper is twofold. First, we model and quantify the value of TCI, and highlight its operational role as linked to the monitoring and shipping decisions. Analyzing this value enables us to offer a theoretical underpinning for the prevalence of different TCI contracts, as well as characterize their relative merits. Second, the findings shed light on how insurers can better design and deploy the most appropriate types of contracts to customers. Our analysis also provides supply chain professionals with insights on how to select the most suitable trade credit insurance policy.

## 2. Related literature

In application, our work is related to two major streams of literature: insurance; and the interface of operations management, finance, and risk management.

In the insurance literature, the main focus has been on the implications of asymmetric information of the insured party, which manifests in the form of adverse selection (e.g., Rothschild and Stiglitz 1976), or moral hazard (e.g., Shavell 1979). Our paper is related to both streams. First, in the literature on moral hazard in the insurance setting, the insured and insurer are equally informed at the time of contracting, yet the insured party may take hidden actions after entering into the contract, and the optimal insurance contract is designed to induce more efficient actions, with deductibles as a commonly used mechanism. Winter (2013) provides an excellent overview of the literature on insurance with moral hazard. Our work contributes to this literature in three respects. First, to the best of our knowledge, all extant work models only the moral hazard associated with *the insured party's* actions. In our paper, however, as the trade credit insurer plays an active risk monitoring role, the optimal contract needs to mitigate not only the supplier's moral hazard (shipping decision), but also the moral hazard associated with the insurer's monitoring effort. As such, we find that a traditional contract (a non-cancelable contract with only a deductible) may be inefficient to mitigate these moral hazards, and granting the insurer a cancellation option often improves the contract performance.

Second and relatedly, depending on whether the moral hazard takes place before or after the focal uncertainty is realized, the extant literature examines either only ex-ante moral hazard, such as underinvesting in precautionary measures (Hölmstrom 1979); or only ex-post moral hazard, such

as overspending on medical care when health conditions cannot be contracted upon (Zeckhauser 1970, Ma and Riordan 2002). Differently, our model considers both ex-ante moral hazard (the insurer's monitoring effort) and ex-post ones (the supplier's shipping decision, and the insurer's cancelation decision under cancelable contracts). Further, the insurer's effort results in information revelation, the value of which depends directly on the supplier's shipping decision. As such, the two moral hazards need to be mitigated jointly, and the resulting dynamics are qualitatively different to those studied in the literature and warrant the different contract forms in TCI.

Third, unlike the literature in which the existence of moral hazard is independent of the contract used, we study a setting in which moral hazard is endogenous to the contract form. In particular, the cancelable contract results in the new moral hazard that allows the insurer to cancel the insurance coverage when it is efficient to ship. This moral hazard, which is absent in a non-cancelable contract, helps explain why and when the non-cancelable contract can be the preferred contract form.

By examining the case where the information that the insurer acquires is unverifiable (§7), our paper is also related to the adverse selection problem in insurance. In the literature, the adverse selection problem arises due to the insured party's private information before contracting, and the main issue is how the insurer can use contracts to screen such information. Differently, our model features the insurer acquiring private information after contracting. As such, the insurer needs to use a credible message to convey his private information, which is modeled as a signaling game embedded in the aforementioned moral hazard setting. Our result here also sheds light on the choice between different contract forms.

Highlighting the operational value of TCI, our work is also related to the fast-growing field of the interface of operations management, finance, and risk management (e.g., Babich and Sobel 2004, Dada and Hu 2008, Boyabatlı and Toktay 2011). Within this stream, our work is most related to the papers on the interaction between insurance and operations. Dong and Tomlin (2012) characterize a firm's optimal inventory policy in the presence of business interruption (BI) insurance. Serpa and Krishnan (2017) also examine BI insurance, focusing on its strategic role in mitigating free riding. Similar to Serpa and Krishnan (2017), our paper is also built on a game-theoretic model. Differently, we study trade credit insurance, another sector of insurance closely related to supply chain management. Because of this setting, we focus on the strategic interaction between the supplier and the insurer, who serves the dual-role of monitoring and cash smoothing, and study its implications for contract forms. Our paper is also related to recent papers on the interaction between agency conflict, operational decisions, and financial contracting (Alan and Gaur 2018, Tang et al. 2018, Babich et al. 2017), especially those that focus on risk shifting as the main source of financial friction. Risk shifting under financial contract has been well recognized in finance (Jensen and Meckling 1976, Myers 1977), and it has been recently studied in the OM in the context of

inventory (Chod 2016, Iancu et al. 2016), pricing (Besbes et al. 2017), and R&D investment (Ning and Babich 2018) under external financing. In our paper, once the insurance contract is in place, the two contracting parties' behavior may deviate from the first-best, similar to the risk shifting behavior studied in the above papers. However, our paper differs from the above ones not only in the context (TCI), but also in the underlying economic mechanism: first, since cancelable contracts involve recourse to updated information, the risk-shifting behavior may arise from both parties in the game; second, in our paper, the risk shifting behavior originates from the updated information generated endogenously by the insurer's moral hazard. Thus, in our model, risk shifting interacts with moral hazard. In addition, this work is related to papers on trade credit (Babich and Tang 2012, Kouvelis and Zhao 2012, Peura et al. 2017, Yang and Birge 2018, Chod et al. 2019, Devalkar and Krishnan 2019), and those on operational and financial means of mitigating supply chain risk (Gaur and Seshadri 2005, Swinney and Netessine 2009, Yang et al. 2009, Turcic et al. 2015).

Conceptually, since the paper captures the moral hazard on both the insurer and the supplier side, our paper is related to the literature on double moral hazard, which has been studied in economics (Bhattacharyya and Lafontaine 1995), and in operations (Corbett et al. 2005, Roels et al. 2010, Jain et al. 2013). In general, this literature studies moral hazards that are effectively simultaneous, and thus focuses on performance-based contracts and sharing contracts, which are static in nature and do not require or possess the ability to incorporate any information updates. In contrast, in our problem, the moral hazards play out sequentially. In particular, the monitoring effort of the insurer results in informational gains, which could cause the supplier's and insurer's subsequent moral hazards; consequently, we examine a form of contract with recourse (the option to cancel) by incorporating the monitoring-generated update. This reactive role is exactly the purpose served by the cancelability feature in TCI contracts.

### 3. Model

The model focuses on the strategic interaction between a supplier (she) who offers trade credit to her buyer and an insurer (he) who offers a TCI product to the supplier which protects her in the event the buyer defaults on the payment. The buyer does not make any decisions in our model.

#### 3.1. The supplier and the buyer

The supplier receives an order from a buyer who agrees to purchase one unit of a good from the supplier at credit price  $r$ , but is prone to payment default. That is, the buyer is obliged to pay the supplier an amount  $r$  at a specified point in time after the good is delivered; however, there is a risk that the buyer may default on the payment. Let the buyer's default risk when the contract is signed be  $\bar{\beta}$ . Upon default, the supplier receives no money from the buyer.

To protect herself against payment default, the supplier may purchase insurance. After signing the insurance contract, if the supplier learns that the buyer's default risk has deteriorated, she may then choose not to ship the good on credit, and instead dispose of the good through an alternative channel (the supplier's outside option) at price  $r_0$ , which is assumed to be lower than  $(1 - \bar{\beta})r$ . That is, the buyer is *a priori* creditworthy. Thus, offering trade credit to the buyer at price  $r$  is *ex ante* more profitable than the outside option if the supplier is not financially constrained.

The supplier's objective is to maximize her (expected) payoff, which includes the incoming revenue and insurance claim payments, and the outgoing insurance premium and financing-related costs. Without loss of generality, the risk-free interest rate is normalized to zero. We leave the details of the insurance premium and claim payment to §3.3, but characterize the supplier's financing costs as follows. As documented in the finance literature (Kaplan and Zingales 1997, Hennessy and Whited 2007, Shleifer and Vishny 2011), when firms face a cash shortfall, for example, due to the buyer defaulting, they incur external financing costs due to various financial market imperfections such as transaction costs (e.g., in asset fire sales). The existence of such costs demands that firms manage cash flow uncertainty using various risk management tools such as hedging and insurance (Froot et al. 1993, Dong and Tomlin 2012). Specifically, we assume that the supplier's financing cost is  $L(x) = l(T - x)^+$ , where  $x$  represents the supplier's (end of period) *net cash flow*, which is equal to her revenue minus the insurance premium and insurance deductible (if applicable), and  $l$  is the marginal financing cost that the supplier incurs if  $x$  falls short of an exogenously specified threshold  $T$ , which captures the severity of the supplier's financial constraint. This financing cost model is an abstraction of several commonly observed frictions that firms face in reality (e.g., fire sale discount). Despite the end-of-period financial constraint  $T$ , the firm has sufficient short-term liquidity to cover the insurance premium in the midst of the period.

On the buyer side, we assume that the buyer's credit risk is evolving between the time when the supplier and the buyer enter the credit sale contract and that when the supplier ships the order. Specifically, by the time that the supplier needs to decide whether to ship the order or not, the buyer's default risk could be one of three levels: low, medium, or high,<sup>3</sup> with corresponding default probabilities  $\beta'_1$ ,  $\beta'_2$ , and  $\beta'_3$ , where  $0 \leq \beta'_1 \leq \beta'_2 \leq \beta'_3$ . The probability that the buyer's default probability is  $\beta'_i$  is  $\theta'_i$ , where  $\sum_i \theta'_i = 1$  and  $\bar{\beta} = \sum_i \theta'_i \beta'_i$ . As modeled later, TCI plays an important role in obtaining information ("signals") regarding this evolving default risk.

<sup>3</sup> Our analysis shows that in order to capture the potential shortcomings of the cancelable contracts, we need at least three risk levels. Furthermore, additional analytical and numerical results confirm that the main insights of the paper continue to hold if we consider a model with  $N > 3$  risk levels.



### 3.2. The trade credit insurer and risk monitoring

To capture the market structure of the TCI industry and to focus on the operational implications of TCI, we assume that the insurer is risk-neutral, faces no liquidity constraint, and operates in a competitive insurance market (Winter 2013). Therefore, the insurer is willing to offer insurance contracts as long as the premium covers his expected cost.

A salient feature of our model is that we capture the insurer's risk monitoring action. Specifically, we assume that after entering the insurance contract, the insurer decides whether to exert unverifiable monitoring effort at a cost  $c \geq 0$ . By exerting effort, with probability  $\lambda \in (0, 1)$ , the insurer can obtain updated information ("signals") that about the buyer's *evolving* default risk in a timely manner before the supplier's shipping decision. Specifically, the signals that the insurer obtains can be classified into three categories, corresponding to the three levels of the buyer's default risk (low, medium, and high) as characterized above: a signal in the low risk group ( $i = 1$ ) reflects that the buyer is operating as usual with its default risk under control, including the case when no risk-aggravating events are discovered. A signal embodying medium risk ( $i = 2$ ) captures the scenario in which there are some worrying signs about the buyer's creditworthiness. Finally, a signal within the high risk group ( $i = 3$ ) shows strong evidence suggesting that a credit sale is overly risky (e.g., filing for bankruptcy). However, with probability  $(1 - \lambda)$ , the insurer fails to obtain any signal, which cannot be distinguished from the scenario when no negative information is observed ( $i = 1$ ).<sup>4</sup> Thus, based on the Bayes' Rule, when obtaining a signal belonging to group  $i = 1$  or no signal at all, which are not distinguishable from each other, the posterior buyer default probability is  $\beta_1 = (1 - \lambda)\bar{\beta} + \lambda\beta'_1$ . The probability of this scenario happening is  $\theta_1 = (1 - \lambda) + \lambda\theta'_1$ . When obtaining a signal of medium or high level, the buyer's posterior default probability  $\beta_i = \beta'_i$  for  $i = 2, 3$ . The probability of these scenarios happening is  $\theta_i = \lambda\theta'_i$  for  $i = 2, 3$  respectively. On the other hand, if the insurer decides not to exert effort, no updated information is observed, and the posterior buyer default probability remains the same as the prior,  $\bar{\beta}$ . We note that the above information generation model is similar to that in Stein (2002), and is consistent with the classic moral hazard literature in that one cannot use the outcome to determine whether the insurer has exerted effort, and thus, effort cannot be directly contracted upon.

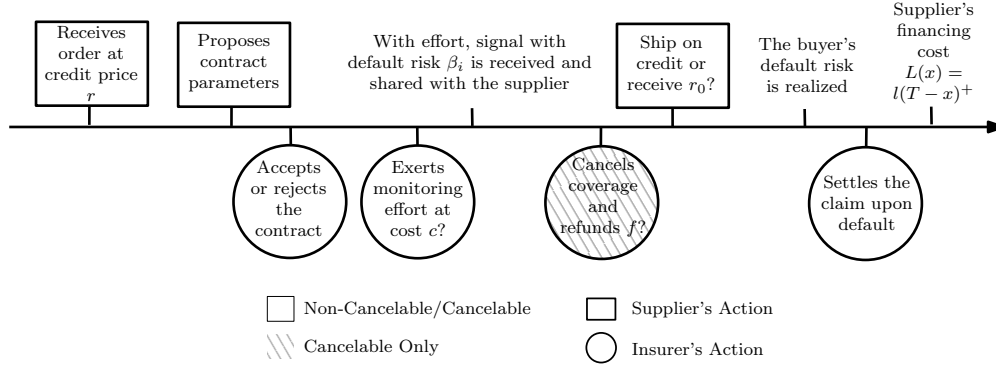
Finally, depending on whether the information obtained is verifiable or not, we consider two scenarios regarding how the insurer shares the information with the supplier. In §5 – 6, we focus on the case when information is verifiable and cannot be strategically manipulated by the insurer. This is largely consistent with our understanding of practice (e.g., the insurer's and supplier's IT systems are partially connected), and it allows us to focus on the moral hazard associated with the insurer fulfilling his monitoring role. In §7, we examine the scenario where the information obtained is unverifiable and the insurer may strategically manipulate information.

<sup>4</sup> We note that this inefficiency exists irrespective of whether the information (signal) is verifiable or not.

### 3.3. TCI contracts

Motivated by industry practice (Association of British Insurers 2016, AIG 2013, Jones 2010, Thomas 2013), we mainly focus on the following two types of TCI contracts, with the corresponding sequence of events as depicted in Figure 1.

**Figure 1** Sequence of events under non-cancelable and cancelable policies.



- **Non-cancelable TCI:** Under a non-cancelable contract, the supplier proposes the deductible  $\delta$  and premium  $p$ , and the insurer decides to accept or reject the contract. After the contract is signed, the supplier pays  $p$  to the insurer, and the insurer may choose to exert monitoring effort at a cost  $c > 0$  and share his findings with the supplier. However, regardless of the insurer's effort decision and the signal that he receives, as long as the supplier ships the order, the insurer must pay the supplier's claim  $r - \delta$  in the event of the buyer defaulting, and pay zero otherwise.

- **Cancelable TCI:** Cancelable contracts differ from non-cancelable ones in two respects. First, the contract includes not only  $p$  and  $\delta$ , but also a refund of the premium  $f \in [0, p]$ . Second, the insurer has the option to cancel the insurance at any time before the good is shipped. If he cancels the coverage, the insurer refunds the supplier  $f$  and removes his exposure to the buyer's credit risk. If he does not cancel, the insurer pays the supplier  $r - \delta$  if the buyer defaults. We refer the readers to TATA-AIG (2017) for the policy wordings used in a typical cancelable contract.<sup>5</sup>

As insurance market is assumed to be competitive, the equilibrium insurance contract is the one that leads to the highest payoff to the supplier, which we define as the optimal contract. Relatedly, we say the shipping decision is *efficient* if and only if the supplier ships under all signals  $i$  with  $(1 - \beta_i)r \geq r_0$ , the shipping policy under the centralized benchmark as shown later.

<sup>5</sup> While allowing different forms of TCI contracts to have different degrees of flexibility, we assume that the two parties cannot explicitly contract on the realization of the signals. This captures the fact that as the insurer draws information from multiple sources, it is impractical to write a complete contract that is contingent on all possible realizations of the signals. We refer the reader to the seminal work of Grossman and Hart (1986) on the difficulties of contracting on complex events.

Finally, to focus on the connection between the operational and financial aspects of the model. We make two technical assumptions. The first one is:

ASSUMPTION 1.  $r_0 > (1 - \beta_3)r$ .

This assumption asserts that the outside option is more profitable than shipping to the riskist buyer, as otherwise the outside option is valueless and obtaining updating information does not have any operational implications. Further, we note that as  $\beta_1 < \bar{\beta}$ , the earlier condition that  $r_0 < (1 - \bar{\beta})r$  also implies that upon receiving updated information, it is always efficient to ship at signal  $i = 1$ . Combined, these assumptions guarantee that obtaining updated information has operational value. Moreover, we note that the efficient decision at  $i = 2$  depends on the attractiveness of  $r_0$  relative to  $\beta_2$ . In the rest of the paper, we refer to the case  $r_0 > (1 - \beta_2)r$  as the attractive outside option case, or equivalently, it is not efficient to ship at  $i = 2$ , and the case  $r_0 \leq (1 - \beta_2)r$  as the unattractive outside option case, i.e., shipping at  $i = 2$  is inefficient.

Second, we assume that the supplier incurs financing costs only if she ships to a buyer who later defaults. A sufficient condition to assure this is characterized as follows.

ASSUMPTION 2.  $T \in [0, r_0 - (r - r_0))$ .

As the insurance premium never exceeds  $(r - r_0)$ , Assumption 2 guarantees that the supplier does not incur financing costs when purchasing insurance and then selling to the outside option.

#### 4. The dual roles of TCI and its potential value

Before analyzing the performance of different TCI contracts, we first establish the potential economic value of TCI by comparing two benchmarks: The centralized benchmark, where the supplier's and insurer's actions are both controlled by a central decision-maker who is financially unconstrained (as the insurer) and maximizes the sum of the two parties' payoffs; and the no-insurance benchmark, where the supplier does not have access to any TCI product. In our setting, the centralized outcome is equivalent to the first-best outcome, i.e., when the players maximize self-interest but all actions are contractible (no moral hazard). The difference in the system surplus between the two benchmark scenarios represents the potential value of TCI, which is formalized in the result below.

PROPOSITION 1. *The potential value of TCI is  $\min\{\bar{\beta}L(0), (1 - \bar{\beta})r - r_0\} + (\phi - c)^+$ , where  $\phi = \sum_{i=1}^3 \theta_i[r_0 - (1 - \beta_i)r]^+$  is the option value of shipment cancelation.*

Proposition 1 reveals that the potential value of TCI has two components: the cash flow-smoothing value  $\min[\bar{\beta}L(0), (1 - \bar{\beta})r - r_0]$  and the monitoring value  $(\phi - c)^+$ . First, like other forms of insurance, TCI smoothes the insured firm's cash flow and lowers the cost associated with the supplier's

financial constraint. Specifically, without insurance, two possible outcomes arise due to the financing constraint: The supplier either ships to the risky buyer under all circumstances, and incurs an (expected) financing cost  $\bar{\beta}L(0)$ , or the supplier always ships to its outside option and incurs an opportunity cost  $(1 - \bar{\beta})r - r_0$ . TCI eliminates such costs by smoothing the supplier's cash flow. Intuitively, such a value is greater when the supplier is more financially constrained (larger  $l$  or  $T$ , and thus greater  $L(0)$ ) or faces a less attractive outside option (lower  $r_0$ ).

Second, and more importantly for our purposes, TCI also plays a monitoring role, which is unique in the TCI setting due to the insurer's superior capability (relative to the supplier) in acquiring and analyzing information. Specifically, by exerting costly effort, the insurer obtains updated information about the buyer's default risk. This enables the supplier to cancel shipping upon receiving a signal  $i$  such that shipping to the outside option generates a higher payoff than to the original risky buyer, i.e.,  $r_0 > (1 - \beta_i)r$ . This option to cancel shipping creates an operational value of  $\phi = \sum_{i=1}^3 \theta_i [r_0 - (1 - \beta_i)r]^+$ . Whenever this value is greater than the cost of monitoring  $c$ , exerting monitoring effort is efficient. To avoid the uninteresting case where it is not efficient for the insurer to exert monitoring effort even in the absence of agency issues ( $c > \phi$ ), the rest of the paper focus on the regions where  $c \leq \phi$ .

While the potential value of both roles of TCI is fully realized under a centralized setting, under a decentralized setting where both the insurer and supplier act to maximize their own interest respectively, it is expected that the realized value of TCI would depend on whether the insurance contract can successfully fulfill the two roles of TCI. In particular, note that fulfilling the monitoring value of TCI depends on the insurer's incentive to invest in monitoring, as well as the supplier's willingness to ship efficiently based on the updated information. These two incentive issues are intertwined, and together they act as the main driving force behind the efficiency of different TCI contracts, which is the focus of the following sections. There, we say the supplier receives the full value of the TCI if the supplier's payoff under a TCI contract equals that under the centralized benchmark. Otherwise, the supplier only receives partial value of the TCI.

## 5. Non-cancelable contracts

We start our analysis by examining the performance of non-cancelable contracts, which are the norm in other insurance sectors. In this section, we first identify the conditions that incentivize the insurer to exert effort (§5.1), and then characterize the optimal non-cancelable contracts (§5.2).

### 5.1. Inducing the insurer's effort

After entering into a contract with premium  $p$  and deductible  $\delta$ , and having obtained an updated estimate of the buyer's default risk,  $\beta_i$ , the supplier makes her shipping decision. Under  $\beta_i$ , if the supplier ships the order, her expected payoff is  $(1 - \beta_i)r + \beta_i [r - \delta - L(r - \delta - p)]$ , where  $L(r - \delta - p)$

is the financing cost in the event of the buyer defaulting. If she does not ship, her payoff is simply her outside option  $r_0$ . By comparing the two options, the supplier ships the order if and only if the payoff from shipping exceeds her outside option, i.e.,  $r - \beta_i [\delta + L(r - \delta - p)] \geq r_0$ , or equivalently,

$$\beta_i \leq \mathbb{B}(p, \delta) := \frac{r - r_0}{\delta + L(r - \delta - p)}, \quad (1)$$

where function  $\mathbb{B}(p, \delta)$  represents the threshold default risk at which the supplier is indifferent between shipping or not under contract  $(p, \delta)$ . For brevity, we suppress the dependence on  $(p, \delta)$ . This condition reflects the intuition that the supplier is more willing to ship when facing a lower deductible. In anticipation of the supplier's shipping decision under contract  $(p, \delta)$ , the insurer's decision to exert monitoring effort is governed by the conditions in Lemma 1.

LEMMA 1. *Under  $(p, \delta)$ , the insurer exerts monitoring effort if and only if all of the following three conditions are satisfied:*

$$\mathbb{B} \geq \bar{\beta}; \quad (2)$$

$$\bar{\beta}(r - \delta) \geq c + (r - \delta) \sum_i \theta_i \beta_i \mathbb{1}_{\beta_i \leq \mathbb{B}}; \quad (3)$$

$$p \geq c + (r - \delta) \sum_i \theta_i \beta_i \mathbb{1}_{\beta_i \leq \mathbb{B}}. \quad (4)$$

The conditions reveal that the insurer's monitoring incentive is closely connected to the supplier's shipping decision under coverage. Specifically, the indicator function  $\mathbb{1}_{\beta_i \leq \mathbb{B}(p, \delta)}$  governs whether the supplier ships when receiving signal  $\beta_i$ . Equations (2) and (3) are the insurer's incentive compatibility constraints. Specifically, for the insurer to exert effort, his cost of doing so must be lower than his cost without effort, in which case the supplier makes her shipping decision based on the prior belief expectation  $\bar{\beta}$ . Clearly, if the supplier does not ship without receiving any updated signal when she is under coverage, i.e.,  $\bar{\beta} > \mathbb{B}$ , then the insurer's cost without effort is zero, which is lower than his cost with effort. Thus, the contract must satisfy (2) for the insurer to exert effort. Under this condition, the supplier always ships without updated information, which leads to the insurer's total cost without effort being  $\bar{\beta}(r - \delta)$ , and (3) guarantees that this cost must be greater than his total cost with effort, which is equal to the sum of the effort cost  $c$  and the expected claim payment when the supplier ships under any  $\beta_i$  that is no greater than  $\mathbb{B}$ . Lastly, the insurer's participation constraint (4) states that the premium  $p$  must cover his total expected cost under monitoring.

## 5.2. The optimal non-cancelable contract and its limitations

After characterizing the condition under which the insurer exerts effort, we identify the optimal contract by comparing the contracts that could not induce monitoring and those that do.

LEMMA 2. *Among all non-cancelable contracts that do not induce the insurer's effort, the optimal one satisfies  $p = \bar{\beta}(r - \delta)$ , where the deductible  $\delta$  is sufficiently small. Under this contract, the supplier always ships to the credit buyer and her expected payoff is  $\Pi_0 = (1 - \bar{\beta})r$ .*

Intuitively, without insurer's monitoring effort, the TCI contract focuses on fulfilling its smoothing role. To achieve that, the deductible has to be sufficiently low such that the supplier avoids financing costs. Further, the low deductible also induces the supplier to ship regardless of the market signal, which in turn discourages the insurer to exert effort.

Next, we characterize the optimal contract among the ones that induce the insurer's effort. After incorporating her optimal shipping decision under this contract, the supplier's objective is:

$$\max_{p, \delta \in [0, r]} -p + r_0 \sum_i \theta_i \mathbb{1}_{\beta_i > \mathbb{B}} + \sum_i \theta_i \{(1 - \beta_i)r + \beta_i[r - \delta - L(r - \delta - p)]\} \mathbb{1}_{\beta_i \leq \mathbb{B}}. \quad (5)$$

As shown, the supplier's expected payoff consists of three parts: The insurance premium  $p$ ; her revenue when she does not ship ( $\beta_i > \mathbb{B}$ ); and her expected revenue when she ships ( $\beta_i \leq \mathbb{B}$ ). The last part further comprises of two components: The supplier's expected revenue when the buyer does not default  $(1 - \beta_i)r$  and her expected payment from the insurer  $\beta_i(r - \delta)$ , as well as her expected financing cost  $\beta_i L(r - \delta - p)$  if the buyer defaults. Solving (5) subject to (2) – (4) leads to the optimal contract that induces the insurer's effort.

By comparing the optimal contract with the insurer's effort in the previous section and the one without (Lemma 2), we can obtain the optimal non-cancelable contract. For brevity, we focus on the optimal contract when the supplier's outside option is attractive. Specifically, Proposition 2 presents the case when the outside option is attractive ( $r_0 > (1 - \beta_2)r$ ). The case where the supplier faces an unattractive outside option ( $r_0 \leq (1 - \beta_2)r$ ), as summarized in Proposition B.1 in the Appendix, is qualitatively similar.

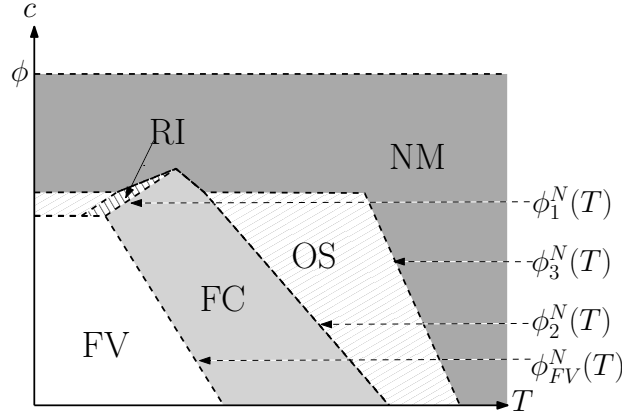
PROPOSITION 2. *When the supplier's outside option is attractive ( $r_0 > (1 - \beta_2)r$ ),*

*i) for  $c \leq \phi_{FV}^N(T) = \phi - \left(\frac{\beta_3}{\beta_2} - 1\right)(r - r_0) - \left[T - (1 - \bar{\beta})\left(r - \frac{r - r_0}{\beta_2}\right)\right]^+$ , the supplier receives the full value of TCI under the optimal contract, and ships only at  $i = 1$ ;*

*ii) for  $c > \phi_{FV}^N(T)$ , the supplier fails to receive the full value of TCI under any non-cancelable contracts. Specifically, there exist threshold functions  $\phi_1^N(T)$ ,  $\phi_2^N(T)$ ,  $\phi_3^N(T)$ , and  $\phi_4^N(T)$  where  $\phi_4^N(T) \geq \dots \phi_1^N(T) \geq \phi_{FV}^N(T)$  such that the supplier's and insurer's actions under the optimal non-cancelable contract are summarized in the following table. Columns 5 and 6 in the table indicate the existence of two potential sources of inefficiency that the supplier may experience.*

Region name	Range of $c$	Insurer monitors	Supplier ships if	Supplier incurs financing cost?	Insurer extracts rent?
Financing Cost (FC)	$(\phi_{FV}^N, \phi_1^N] \cup (\phi_3^N, \phi_4^N]$	Yes	$i = 1$	Yes	No
Rent to Insurer (RI)	$(\phi_1^N, \phi_2^N]$	Yes	$i = 1$	Yes	Yes
Over-Shipping (OS)	$(\phi_2^N, \phi_3^N]$	Yes	$i = 1, 2$	Sometimes	No
No Monitoring (NM)	$(\phi_4^N, \phi]$	No	$i = 1, 2, 3$	No	No

**Figure 2** Illustration of different regions under the optimal non-cancelable contract when  $r_0 > (1 - \beta_2)r$ .



Notes. Different regions correspond to Column 1 in Proposition 2. In this illustrative example,  $\phi_3^N(T) = \phi_4^N(T)$ . See the proof of Proposition 2 for the definition of  $\phi_1^N(T)$ ,  $\phi_2^N(T)$ ,  $\phi_3^N(T)$ , and  $\phi_4^N(T)$ .

The different regions in Proposition 2 is illustrated in Figure 2. The specific contract terms and the supplier's and insurer's payoffs are cumbersome and are left in the proof for brevity. We note from  $\phi_{FV}^N(T)$  that under the optimal contract, the supplier receives the full value of TCI when both  $c$  and  $T$  are small, while facing various types of operational and financial inefficiencies as either  $c$  or  $T$  becomes larger. To see why, recall that the role of TCI consists of two components: smoothing and monitoring. Fulfilling both imposes divergent forces on the deductible  $\delta$ . On the one hand, to unlock the smoothing value of TCI, the deductible needs to be sufficiently low, as otherwise, the supplier incurs financing costs even under coverage. On the other hand, the monitoring role requires the supplier to ship efficiently based on the updated information. To deter the supplier from taking excessive risks, the deductible should be reasonably high. This tension intensifies as the supplier's financial constraint becomes more stringent (large  $T$ ), deeming it impossible for the supplier to recover the full value of TCI. Instead, the optimal contract may require a high deductible in order to enforce the efficient shipping policy, which results in financing costs (Region  $FC$ ). Alternatively, if the deductible is kept low in order to reduce financing costs, the optimal contract then has to allow the supplier to adopt a more aggressive shipping policy (Region  $OS$ ).

Eventually, when  $T$  is extremely large, it becomes too costly to fulfill the monitoring role of TCI, resulting in the no-monitoring contract as captured Lemma 2 to be the optimal one (Region  $NM$ ).

More interestingly, setting aside the smoothing role, the monitoring role also imposes two conflicting forces on deductible. As mentioned above, the deductible needs to be sufficiently high to induce efficient shipping. However, as the monitoring role also requires the insurer to exert effort, the deductible cannot be too high. This is captured in (3): When the deductible is very high, the negative impact of the buyer's default on the insurer is minimal, and thus dulls the insurer's incentive to monitor. Such tension is more pronounced when the insurer's cost of effort is high (large  $c$ ). Specifically, as  $c$  increases, (3) calls for a lower deductible. As the cost of effort is sufficiently close to the potential benefit of monitoring  $\phi$ , it is impossible to fully recover the monitoring role. Thus, the optimal contract adopts one of three alternatives. First, to induce both monitoring effort and efficient shipping, the contract needs to set the deductible at a level such that the insurer's participation constraint (4) is not binding. In other words, the supplier surrenders some rent to the insurer (Region  $RI$ ). Alternatively, similar to the case with large  $T$ , the optimal contract may also lead to over-shipping (Region  $OS$ ), or abandoning monitoring (Region  $NM$ ).

At a high level, the inefficiency in the optimal non-cancelable contracts is related to the mismatch between the sequential nature of the incentive conflict under TCI and the static nature of the contract. Specifically, the monitoring role of TCI relates to the sequential actions of the insurer and the supplier: The supplier's decision to ship or not is contingent on the specific information that the insurer acquires. However, as the single lever in the contract to mitigate both moral hazards, deductible is specified before the information update. As such, it is often inadequate for mitigating the conflicts of interest between the two parties.

## 6. Cancelable contracts

In this section, we examine cancelable contracts and investigate whether they may mitigate some of limitations of non-cancelable contracts. Clearly, the insurer's option to cancel the coverage is only valuable when he acquires updated information and when he actually exercises this option under certain circumstances. Thus, in this section, we limit ourselves to those contracts under which the insurer exerts monitoring effort, and actually cancels coverage upon receiving certain signals.

### 6.1. The interplay between supplier's shipping and insurer's cancelation decisions

To identify the optimal cancelable contract, we first characterize the supplier's shipping policy and then the insurer's cancelation policy under a given insurance contract  $(p, \delta, f)$ , where  $f \in [0, p]$  is the refund that the insurer pays to the supplier upon cancelation of the insurance policy.

Depending on whether her coverage is canceled, the supplier's shipping policy can be discussed in two scenarios. First, when insurance coverage is not canceled, the supplier's payoff under signal



$i$  is  $r - p - \beta_i[\delta + L(r - \delta - p)]$  if she ships, and  $r_0$  if she does not ship. Hence, the supplier ships the order if and only if  $\beta_i \leq \mathbb{B}(p, \delta)$  where  $\mathbb{B}(\cdot)$  was introduced in Eq. (1).

In the case that the insurance is canceled, under the signal  $i$ , the supplier's payoff is  $r - p + f - \beta_i[r + L(f - p)]$  if she ships, and  $r_0 - p + f$  if she does not. Comparing the two payoffs, the supplier ships if and only if:

$$\beta_i \leq \mathbb{B}_C(p, f) := \frac{r - r_0}{r + L(f - p)}, \quad (6)$$

where the subscript  $C$  represents that the coverage is *canceled*. Note that as  $L(\cdot) \geq 0$ ,  $\mathbb{B}_C \leq (r - r_0)/r$ ; this captures the intuition for how the cancelation of coverage could deter the supplier from over-shipping.

In anticipation of the supplier's shipping decision described above, the insurer decides whether or not to cancel coverage. Since the insurer must refund  $f$  to the supplier upon cancelation, he never cancels when  $\beta_i > \mathbb{B}$ , for which the supplier would never ship the order even under coverage. However, if the supplier does ship the order when coverage is not canceled ( $\beta_i \leq \mathbb{B}$ ), the expected claims cost to the insurer is  $\beta_i(r - \delta)$ . Balancing this cost and the refund  $f$ , the insurer cancels coverage if and only if  $\beta_i \in [\mathbb{B}_P, \mathbb{B}]$ , where

$$\mathbb{B}_P(\delta, f) := \frac{f}{r - \delta}, \quad (7)$$

and the subscript  $P$  represents the insurer's cancelation *policy*. Thus, the insurer only cancels the coverage when the buyer's default risk is in the middle range. At the low end, the risk is low relative to the refund, while at the high end, the supplier herself stops shipping. That said, the upper threshold  $\mathbb{B}$  may be higher than  $\beta_3$  when the deductible is sufficiently small, at which point the insurer's cancelation policy degenerates to a simple threshold policy.

**LEMMA 3.** *Under any cancelable contract in which the insurer exerts effort and actually cancels coverage at certain signals,  $\mathbb{B} > \max(\mathbb{B}_C, \mathbb{B}_P)$ , and the supplier ships if and only if  $\beta_i < \max(\mathbb{B}_C, \mathbb{B}_P)$ .*

The above result suggests that the supplier's shipping policy may be completely aligned with the insurer's cancelation policy (when  $\mathbb{B}_C \leq \mathbb{B}_P$ ), yet she may also ship when the coverage is canceled ( $\mathbb{B}_C > \mathbb{B}_P$ ). Under either case,  $\mathbb{B} > \max(\mathbb{B}_C, \mathbb{B}_P)$  confirms the intuition that a cancelable contract induces the supplier to ship to the credit buyer more conservatively than without the cancelation option. As a cancelable contract under which the insurer never cancels the coverage is equivalent to a non-cancelable contract, we focus on cancelable contracts which satisfy Lemma 3.

## 6.2. The power of cancelable insurance

Combining the insurer's cancelation and the supplier's shipping decisions, we can characterize the conditions under which a cancelable contract induces the insurer to exert monitoring effort (see Lemma B.1 in the Appendix). These conditions (Eq. (12) – (14)) follow a similar structure as under the non-cancelable case (Lemma 1), but differ in that they incorporate the insurer's cancelation policy. Among the contracts  $(p, \delta, f)$  that satisfy these conditions, it is in the interest of the supplier to choose the one that maximizes her own payoff, that is,

$$\begin{aligned} \max_{\substack{p, \delta \in [0, r] \\ f \leq p}} & -p + \sum_i \theta_i [r - \beta_i(\delta + L(r - p - \delta))] \mathbb{1}_{\beta_i < \mathbb{B}_P} + \sum_i \theta_i [(1 - \beta_i)r - \beta_i L(f - p)] \mathbb{1}_{\beta_i \in [\mathbb{B}_P, \mathbb{B}_C)} \\ & + r_0 \sum_i \theta_i \mathbb{1}_{\beta_i > \max(\mathbb{B}_P, \mathbb{B}_C)} + f \sum_i \theta_i \mathbb{1}_{\beta_i \in [\mathbb{B}_P, \mathbb{B})}. \end{aligned} \quad (8)$$

Eq. (8) shows that under cancelable contracts, the supplier's expected payoff consists of five parts: The insurance premium; her net revenue when shipping under coverage ( $\beta_i < \mathbb{B}_P$ ); that when shipping without coverage ( $\beta_i \in [\mathbb{B}_P, \mathbb{B}_C)$ ); her outside option when she does not ship ( $\beta_i > \max(\mathbb{B}_P, \mathbb{B}_C)$ ); and finally, the refund when the coverage is canceled ( $\beta_i \in [\mathbb{B}_P, \mathbb{B})$ ).

By solving this optimization program, we characterize the optimal contract and the parties' corresponding actions based on whether the supplier's outside option is attractive ( $r_0 \geq (1 - \beta_2)r$ , Proposition 3) and unattractive ( $r_0 < (1 - \beta_2)r$ , Proposition 4 in §6.3).

**PROPOSITION 3.** *When  $r_0 \geq (1 - \beta_2)r$ , the following cancelable contract is optimal:*

$$\delta = 0; \quad p = f = \frac{c}{\theta_1} + \beta_1 r. \quad (9)$$

*Under this contract, the supplier receives the full value of TCI by only shipping at  $i = 1$ . Correspondingly, the insurer cancels the coverage upon receiving signal  $i = 2, 3$ .*

In comparison with the performance of the optimal non-cancelable contract as depicted in Proposition 2, we notice that under the same parameter region ( $r_0 \geq (1 - \beta_2)r$ ), the optimal cancelable contract always enables the supplier to enjoy the full benefit of TCI. The reason is as follows. Recall that the inefficiency of non-cancelable contracts is mostly due to two sets of conflicts that pull the deductible in different directions: The conflict within the monitoring role (large  $c$ ), and the conflict between the smoothing role and monitoring one (large  $T$ ). The cancelable contract, on the other hand, has its advantages in resolving both conflicts. To see how cancelable contracts can fully recover the monitoring role, recall from Lemma 3, the supplier ships more aggressively under coverage than without. Thus, by canceling her coverage, the insurer can effectively nudge the supplier to adopt a more conservative shipping policy. Put differently, a cancelable contract (partly) transfers control over the shipping decision from the supplier to the insurer. Furthermore,

since the insurer does not directly benefit from the upside potential of the trade, the insurer indeed tends to behave more conservatively, which is consistent with the efficient shipping policy when the supplier faces an attractive outside option. Consequently, granting more control to the insurer efficiently deters over-shipping.

Second, by allowing the insurer to cancel coverage, the cancelable contract partially decouples the two roles of TCI by effectively creating two levels of deductible: When the signal deems shipping as efficient ( $i = 1$ ), the supplier is covered by insurance. Under such circumstances, the smoothing role of TCI is fulfilled as the nominal deductible  $\delta$  is kept low. This result is also consistent with the fact that in practice, a majority of cancelable contracts includes zero deductible, while non-cancelable contracts tend to have large deductibles (Euler Hermes 2018). On the other hand, when shipping is inefficient ( $i \geq 2$ ), the full monitoring value of TCI is realized via the cancellation of coverage, which results in an effective deductible equal to  $r$ .

In summary, the value of cancelable contracts lays in its inherently sequential nature. Specifically, the insurer's recourse to cancel is exercised after observing the updated information. Such an *ex post* action is contingent on the realization of the signal, and thus enhances the monitoring value of TCI. In addition, note that the cancellation option can only be exercised before the supplier's shipping decision, as cancellation afterwards does not correspond to any recourse that creates economic value. This is also consistent with the practice that the insurer cannot cancel coverage after the order is shipped.

### 6.3. The peril of cancelable contracts: over-cancellation

While Proposition 3 reveals some merits of the cancelable contracts, such contracts are not without limitation. As shown in the following result, fully recovering the value of TCI is not always feasible under cancelable contracts when the supplier's outside option is unattractive.

PROPOSITION 4. *When the supplier's outside option is unattractive ( $r_0 < (1 - \beta_2)r$ ),*

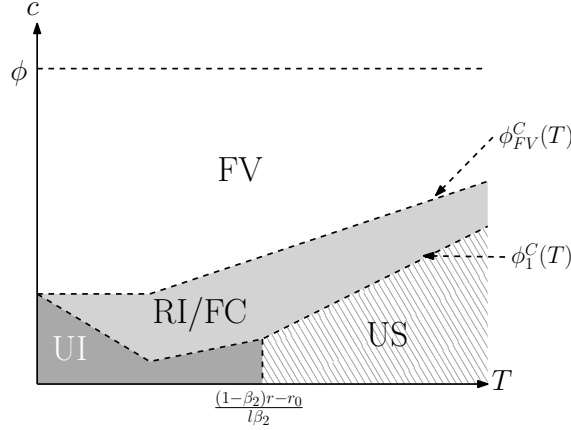
*i) If  $\beta_2 \leq \bar{\beta}$ , there exist threshold functions  $\phi_1^C(T) \leq \phi_{FV}^C(T) = \theta_1(\beta_2 - \beta_1) \max\left(r - \frac{r-r_0}{\beta_3}, \frac{T}{1-\beta_2}\right)$  such that the performance of the optimal cancelable contract is summarized in the following table.*

Region name	Range of $(c, T)$	Insurer cancels if	Supplier ships if	Financing cost	Rent to insurer
Full-Value (FV)	$c \geq \phi_{FV}^C$	$i = 3$	$i = 1, 2$	No	No
RI/FC	$c \in [\phi_1^C, \phi_{FV}^C)$	$i = 3$	$i = 1, 2$	Sometimes	Sometimes
Under-Insured (UI)	$c < \phi_1^C$ and $T \leq \frac{(1-\beta_2)r-r_0}{l\beta_2}$	$i = 2, 3$	$i = 1, 2$	Yes	No
Under-Shipping (US)	$c < \phi_1^C$ and $T > \frac{(1-\beta_2)r-r_0}{l\beta_2}$	$i = 2, 3$	$i = 1$	No	No

*ii) If  $\beta_2 > \bar{\beta}$ , there exist threshold functions  $\phi_2^C(T) \leq \phi_3^C(T)$ , such that the performance of the optimal cancelable contract is summarized in the following table.*

Region name	Range of $(c, T)$	Insurer cancels if	Supplier ships if	Financing cost	Rent to insurer
RI/FC	$c \in [\phi_2^C, \phi_3^C)$	$i = 3$	$i = 1, 2$	Sometimes	Yes
UI	$c \in (0, \phi_2^C) \cup (\phi_3^C, \phi)$ and $T \leq \frac{(1-\beta_2)r-r_0}{l\beta_2}$	$i = 2, 3$	$i = 1, 2$	Yes	No
US	$c \in (0, \phi_2^C) \cup (\phi_3^C, \phi)$ and $T > \frac{(1-\beta_2)r-r_0}{l\beta_2}$	$i = 2, 3$	$i = 1$	No	No

**Figure 3** Illustration of different regions under optimal cancelable contract when  $r_0 < (1 - \beta_2)r$ .



Notes. The illustration is generated under parameters  $\beta_2 \leq \bar{\beta}$ .

Proposition 4 is illustrated in Figure 3. The first notable result is that the supplier fails to recover the full value of TCI when the insurer's monitoring cost is sufficiently low or when the medium signal ( $\beta_2$ ) is deteriorating relative the prior belief.

The reason why a low monitoring cost hurts the performance of cancelable contract, interestingly, also originates from the insurer's cancellation option. While such an option increases the flexibility of the contract, the flexibility is granted to the insurer, and hence may not always benefit the supplier. Indeed, this flexibility creates an additional moral hazard on the insurer's side. Similar to the supplier's tendency to over-ship, once the contract is in place, the insurer exercises his cancellation option according to his own best interest, which may not be fully aligned with the supplier's. Specifically, as previously shown, for the insurer to *not* cancel at signal  $i$ , his cost of cancellation (refund  $f$ ) exceeds the expected claim costs  $\beta_i(r - \delta)$ , i.e.,

$$f \geq \beta_i(r - \delta). \quad (10)$$

This constraint alludes to the two scenarios in which the insurer tends to over-cancel, i.e., cancel at signal  $i$  when  $(1 - \beta_i)r > r_0$ . First, when the supplier's outside option is unattractive (small  $r_0$ ), it remains efficient to ship at some  $i$  when  $\beta_i$  is relatively large. Thus, it is more difficult to satisfy (10) for such  $i$ . Second, when the insurer's monitoring cost is low, the insurance premium

$p$  also tends to be low. As the refund  $f$  is capped by  $p$  in practice, (10) becomes more stringent as  $c$  decreases, which also reduces the insurer's expected cost, holding everything else constant. When both conditions are met, in order to satisfy (10) for any signal  $i$  with  $(1 - \beta_i)r \leq r_0$ , the optimal contracts exhibit one of two possible features: They either have a higher deductible, thereby increasing financing costs; or they have a higher premium to allow a higher refund, which leaves rent to the insurer. These contracts are captured in the Region  $RI/FC$  in Figure 3. As  $c$  further decreases, it becomes too costly to incentivize the insurer to adopt an efficient cancellation policy. Instead, he cancels coverage at  $i = 2, 3$ , although shipping at  $i = 2$  is efficient. In response, the supplier chooses between two alternatives depending on her financial constraints. When she is less concerned about the financing cost (small  $T$ ), the supplier follows the efficient shipping policy, which means that she ships at  $i = 2$  uninsured (Region  $UI$ ). However, for large  $T$ , the supplier cannot afford shipping without insurance. Thus, she does not ship at  $i = 2$  even if it is efficient (Region  $US$ ). Such a dilemma is often faced by suppliers. For example, in 2009, Total Security Systems, a small supplier to UK security companies, had to decide whether to ship an order worth £100,000 after their TCI was canceled. Even though they believed that the buyer's default risk was low, they canceled the order as they were unwilling to ship uninsured (Stacey 2009).

Finally, we note that the inefficiency of cancelable contracts is more pronounced when the credit risk under the medium signal is high ( $\beta_2 \geq \bar{\beta}$ ). In this case, the insurer has a greater tendency to cancel at  $i = 2$ , and the supplier is forced to surrender more rent to the insurer in order to prevent over-cancellation. As such, the parties are more likely to adopt either inefficient cancellation or inefficient shipping policies.

#### 6.4. Contracts choice and improvements

By directly comparing the optimal non-cancelable and cancelable contracts, we note that when the supplier's outside option is attractive, i.e.,  $r_0 \geq (1 - \beta_2)r$ , the supplier always (weakly) prefers the cancelable contract, which recovers the full value of TCI, over the non-cancelable one. The performance of the cancelable contract strictly dominates when the monitoring cost is high, i.e.,  $c > \phi_{FV}^N(T)$  (in Proposition 2). On the other hand, the supplier's preference in the presence of an unattractive outside option is summarized in the following.

**PROPOSITION 5.** *When the outside option is unattractive ( $r_0 < (1 - \beta_2)r$ ):*

1. *For  $\beta_2 \leq \bar{\beta}$ , there exists threshold function  $\phi_L(T)$  such that the supplier prefers the non-cancelable contract with monitoring when  $c \leq \phi_L(T)$ , and the cancelable one when  $c > \phi_L(T)$ .*
2. *For  $\beta_2 > \bar{\beta}$ , there exist threshold functions  $\phi_{H,1}(T) \leq \phi_{H,2}(T)$  such that the supplier prefers the non-cancelable contract with monitoring when  $c \leq \phi_{H,1}(T)$ , and the non-cancelable contract without monitoring when  $c \geq \phi_{H,2}(T)$ .*

The above Proposition confirms that when the outside option is unattractive, the supplier in general prefers the non-cancelable contract when the monitoring cost is sufficiently low.<sup>6</sup> This result echoes the recent emergence of non-cancelable contracts. Due to the adoption of superior information systems and other technological advances, the insurer's monitoring costs are now markedly lower than that in the past. This potentially drives down insurance premiums, and as previously mentioned, a low premium generally leads to over-cancellation by the insurer, which is also consistent with the fact that TCI insurers have been accused of canceling coverage unreasonably. In addition, during the financial crisis, suppliers faced challenging market conditions and were often deprived of attractive outside options. Such situations made suppliers particularly vulnerable to insurers' tendency to over-cancel, making non-cancelable contracts a more desirable choice.

As revealed in the previous results, when choosing TCI contracts, the supplier needs to measure and compare the value of flexibility offered by cancellation, with that of the commitment embodied in non-cancelable coverage. Intuitively, a cancelable contract with part of the coverage being non-cancelable that blends these two benefits may further improve the performance of TCI. This type of contract corresponds to an emerging industry practice of adding non-cancelable coverage onto a cancelable contract, which is sometimes referred to as *top-up cover* on cancelable coverage (Insurance Journal 2012). Such a partially cancelable contract is similar to a cancelable contract with only one difference: upon cancellation, the insurer can only cancel part of the coverage, while the remaining part, is non-cancelable. By modeling this innovative contract form, we find that such contracts further expand the region where the supplier receives the full value of TCI (See Proposition B.2 in the Appendix for details). Our analysis shows that this innovation adds value through two channels: first, it protects the supplier from financing costs through non-cancelable coverage; second, it deters the insurer from over-canceling.

## 7. The implication of unverifiable information

In order to focus on the moral hazard associated with the insurer fulfilling his monitoring role, we assume in the previous sections that once the insurer obtains the updated information through monitoring effort, he shares the information with the supplier without distortion. This assumption is largely consistent with our understanding of practice (e.g., the insurer's and supplier's IT systems are partially connected, thereby making it difficult to distort information). However, there is a possibility that the insurer may strategically manipulate the acquired information, and it is probably more likely when the information is acquired from non-public sources and is thus difficult to verify. This section examines the implication of such unverifiable information. The model,

<sup>6</sup> When  $\beta_2 > \bar{\beta}$  and  $c \in (\phi_{H,1}(T), \phi_{H,2}(T))$ , the dominant contract form depends on specific parameter choices.

including the TCI contracts, is identical to that in §3, except that upon monitoring, the insurer can misrepresent the information that he gathers.

In this setting, we first note that the potential value of TCI is the same as depicted in Proposition 1 since the information is directly available to the insurer. Regarding the performance of TCI contracts when the insurer maximizes his self-interest, it is intuitive that the insurer always has the incentive to misrepresent the information in order to deter the supplier from shipping the order, which would rid him of any claim liability. Anticipating this, the supplier deems valueless any information that the insurer conveys. This in turn discourages the insurer from exerting monitoring effort, and thus unravels the monitoring role of TCI. Thus, under the non-cancelable contract, where the insurer has no other credible means to convey the gathered information to the supplier, the insurer has no incentive to exert effort, and thus fails to fulfill the monitoring role. The resulting optimal non-cancelable contract is the one depicted in Lemma 2 and it is clear that unverifiable information hurts the performance of non-cancelable contracts.

The impact of unverifiable information on cancelable contracts, however, is more intricate. We first note that cancelable contracts equip the insurer with a tool that could potentially convey the gathered information to the supplier, namely, his cancelation action. The intuition is that the cost incurred by the insurer to cancel depends on the information he receives: when the information is positive (low default risk), the cost of cancelation is high, and when negative (high default risk), cancelation is less costly. Thus, when the supplier observes that her coverage is canceled, she is more likely to be convinced that the information that the insurer gathers is negative.

To formalize the above argument, we model the interaction between the insurer and the supplier, after contracting and the insurer having exerted monitoring effort, as a signaling game. The insurer (the sender) conveys his private information to the supplier (the receiver) with the action of cancelation as the message. We refer the readers to Riley (2001) for a review of signaling games in the economics literature, and to Lai et al. (2011), Bakshi et al. (2015), and Tang et al. (2018) for the application in the OM literature. The relevant equilibrium concept is the Perfect Bayesian equilibrium (PBE). In equilibrium, upon observing the insurer's cancelation action (the message), the supplier forms her posterior belief based on the information the insurer gathers, using Bayes' Rule. Thereafter, the supplier makes her shipment decision accordingly. Specific to the TCI setting, we focus on semi-separating equilibria as the number of possible messages (cancel or not cancel) is less than the number of information classes ( $i = 1, 2, 3$ ), and thus it is impossible to completely separate each class of information through different action. The other possible type of equilibria is the pooling equilibria. However, as the insurer has no incentive to exert monitoring under such equilibria, the resulting cancelable contract will be (weakly) dominated by the optimal non-cancelable one.

By studying this signaling game (we refer the readers to Lemma B.2 in the Appendix for details), we find that under the optimal cancelable contract, the insurer adopts an intuitive threshold cancellation policy: He cancels the contract upon receiving negative information, and does not cancel on receiving positive information. In response, the supplier ships if and only if her coverage is not canceled. For the equilibrium outcome in the signaling game, the analysis regarding the insurer's decision to exert monitoring effort and the supplier's choice of contract terms is similar to that in §6. We present the performance of the resulting optimal contract as follows.

PROPOSITION 6. *When the information gathered by the insurer is unverifiable,*

1. *For an attractive outside option ( $r_0 \geq (1 - \beta_2)r$ ), the supplier receives the full value of TCI under the optimal cancelable contract;*
2. *For an unattractive outside option ( $r_0 < (1 - \beta_2)r$ ):*
  - i) *If  $\beta_2 \leq \bar{\beta}$ , there exists threshold functions  $\phi_1^U(T) \geq \phi_{FV}^U(T) = \frac{\theta_1(\beta_2 - \beta_1)T}{1 - \beta_2}$  such that the performance of the optimal cancelable contract is summarized in the following table.*

Region name	Range of $c$	Insurer cancels if	Supplier ships if	Financing cost	Rent to insurer
Full Value (FV)	$[\phi_{FV}^U, \phi]$	$i = 3$	$i = 1, 2$	No	No
RI/FC	$[\phi_1^U, \phi_{FV}^U)$	$i = 3$	$i = 1, 2$	Sometimes	Sometimes
Under-shipping (US)	$[0, \phi_1^U)$	$i = 2, 3$	$i = 1$	No	No

- ii) *If  $\beta_2 > \bar{\beta}$ , there exist threshold functions  $\phi_2^U(T) \leq \phi_3^U(T)$ , such that the performance of the optimal cancelable contract is summarized in the following table.*

Region name	Range of $c$	Insurer cancels if	Supplier ships if	Financing cost	Rent to insurer
RI/FC	$[\phi_2^U, \phi_3^U)$	$i = 3$	$i = 1, 2$	Sometimes	Yes
US	$[0, \phi_2^U) \cup (\phi_3^U, \phi)$	$i = 2, 3$	$i = 1$	No	No

By comparing the optimal cancelable contract under unverifiable information with the counterparts under verifiable information (Propositions 3 and 4), we notice that the cancelable contract remains efficient in the presence of unverifiable information when the supplier faces an attractive outside option ( $r_0 \geq (1 - \beta_2)r$ ). However, in the presence of an unattractive outside option ( $r_0 < (1 - \beta_2)r$ ), while the performance of the optimal cancelable contract follows a structure similar to the verifiable information case, two differences are notable. First, the optimal contract under unverifiable information allows the supplier to receive the full benefit of TCI over a larger range of monitoring costs. This is because when the updated information is unverifiable, the supplier is forced to react to the insurer's action, instead of the information itself. In this way, the insurer gains more direct control, and thus, can partially mitigate the supplier's agency problem. Second, unverifiable information may also hurt the supplier by, interestingly, the same force. Specifically,



when the insurer cancels at both  $i = 2$  and  $3$ , the supplier is unable to distinguish these two cases, and thus loses the potentially valuable option to ship un-insured (Region  $UI$  in Proposition 4).

Finally, Proposition 7 compares the above cancelable contract with the non-cancelable one.

**PROPOSITION 7.** *When the information acquired by the insurer is unverifiable,*

1. *for  $\beta_2 \geq \bar{\beta}$ , the supplier prefers the cancelable contract;*
2. *for  $\beta_2 < \bar{\beta}$ , there exists a threshold function  $\phi_H^U(T)$  such that the supplier prefers the cancelable contract if and only if  $c \leq \phi_H^U(T)$ .*

Relative to the results under verifiable information (Proposition 5), cancelable contracts are more likely to be the dominant contracting form when the gathered information is unverifiable, especially when the monitoring cost is low. This is because that in addition to its role in mitigating moral hazard, the cancelation option, which is only present in cancelable contracts, serves as a credible signal for the insurer to communicate private information. Put differently, if the insurer has other channels through which he can credibly communicate the gathered information to the supplier (e.g., through IT integration, or blockchain), the attractiveness of non-cancelable contracts will be improved, especially under low monitoring cost. This possibly lends another explanation for the growing popularity of non-cancelable contracts.

## 8. Conclusion

TCI is a commonly adopted risk management tool for suppliers who extend trade credit to their buyers. Despite its wide usage in practice, TCI has been largely overlooked in the academic literature. In this paper, we highlight the operational value of TCI, as linked to the monitoring role that the insurer plays in the TCI setting. We also highlight the supplier's and insurer's moral hazards associated with this role. Centered around cancelability, a distinctive feature of TCI contracts, we identify the respective advantages and limitations of the two forms of commonly seen TCI contracts: cancelable and non-cancelable contracts.

Our paper can be extended along different dimensions. For example, in focusing on the insurer-supplier interaction, we assumed that the employment of TCI does not influence the buyer's default probability. However, in some cases, if the supplier were to withdraw the buyer's trade credit upon having her insurance canceled, the buyer may face more severe liquidity constraints and thus be more likely to fail. Similar dynamics (without TCI) were studied recently in Babich (2010) and Yang et al. (2015). Yet, the choice of TCI contract in the presence of endogenous default risk remains an open question. Relatedly, the paper takes the trade credit terms between the supplier and the buyer as exogenously given. However, the availability of TCI could have an impact on the terms between the two trading parties, as well as other financing options. Extending the current

model in this dimension could be a promising direction for future research. Finally, while the paper focuses on TCI, the principles that we uncovered may apply more generally. Specifically, insurer's cancelation option can enhance the value of other types of insurance where the insurer is better equipped to monitor the insured risk. For example, as an emergent insurance product, contingent business interruption (CBI) insurance reimburses lost profits and extra expenses resulting from an interruption of business at the premises of a customer or supplier, and hence also insures a risk that is not internal to the insured party. Therefore, it is possible that the insurer is more efficient at monitoring this risk as well. Thus, our results have the potential to inform risk management practice beyond TCI.

## Acknowledgments

The authors sincerely thank Vishal Gaur, the Associate Editor, three anonymous referees, Vlad Babich, John Birge, Guoming Lai, Rong Li, Nicos Savva, Richard Talboys, Juan Serpa, the seminar participants at Chicago Booth, UCLA Anderson, and University of Toronto Rotman School of Business, the participants of the 2016 POMS Annual Conference, the 2nd Supply Chain Finance and Risk Management Workshop at Washington University in St Louis, the 2016 M&SOM Annual Conference, the 2016 INFORMS Annual Conference, for their valuable inputs and suggestions. The authors are also grateful to London Business School for the generous financial support.

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## Appendix A: List of Notation

Table 1 summarizes the notation used in the paper.

**Table 1**    **Notation**

$r$	the credit price that the supplier charges to the credit buyer
$r_0$	the supplier's outside option, $r_0 < r$
$T$	the supplier's net cash flow threshold (she incurs a financing cost when her net cash flow is below $T$ )
$l$	the proportional financing cost incurred by the supplier
$c$	the insurer's cost of exerting monitoring effort
$\beta_i$	the buyer's default probability when the updated information is of type $i = 1, 2, 3$ . $0 \leq \beta_1 < \beta_2 < \beta_3 \leq 1$
$\theta_i$	the probability that the insurer observes information of group $i = 1, 2, 3$ , $\sum_{i=1}^3 \theta_i = 1$
$\bar{\beta}$	the prior expectation of the buyer's default probability, $\sum_{i=1}^3 \theta_i \beta_i = \bar{\beta}$ ; $(1 - \bar{\beta}) > r_0$
$p$	insurance premium $p \geq 0$
$\delta$	deductible, $\delta \in [0, r]$
$f$	the refund that the insurer pays to the supplier when the insurance is canceled, $f \in [0, p]$
$\phi$	the maximum cost of effort for monitoring to be efficient. $\phi = \sum_{i=1}^3 \theta_i [r_0 - (1 - \beta_i)r]^+$

## Appendix B: Supplemental Results

**Proposition B.1** When the supplier's outside option is unattractive ( $r_0 < (1 - \beta_2)r$ ), there exist threshold functions  $\phi_{FV}^{NL}(T)$ ,  $\phi_1^N(T)$ ,  $\phi_2^N(T)$  and  $\phi_3^N(T)$ , where

$$\phi_3^{NL}(T) \geq \phi_2^{NL}(T) \geq \phi_1^{NL}(T) \geq \phi_{FV}^{NL}(T) = \phi - \left[ T - (1 - \bar{\beta}) \left( r - \frac{r - r_0}{\beta_3} \right) \right]^+, \quad (11)$$

such that the performance of the optimal contract is summarized in the following table.

Region name	Range of $c$	Insurer monitors	Supplier ships if	Supplier incurs financing cost?	Insurer extracts rent?
Full Value (FV)	$[0, \phi_{FV}^{NL}]$	Yes	$i = 1, 2$	No	No
Financing Cost (FC)	$(\phi_{FV}^{NL}, \phi_1^{NL}] \cup (\phi_2^{NL}, \phi_3^{NL}]$	Yes	$i = 1, 2$	Yes	No
Under-Shipping (US)	$(\phi_1^{NL}, \phi_2^{NL}]$	Yes	$i = 1$	Sometimes	Sometimes
No Monitoring (NM)	$(\phi_3^{NL}, \phi]$	No	$i = 1, 2, 3$	No	No

**Lemma B.1** Under a cancelable contract  $(p, \delta, f)$ , the insurer exerts monitoring effort if and only if all of the following conditions are satisfied:

$$\mathbb{B} \geq \bar{\beta}; \quad (12)$$

$$\bar{\beta}(r - \delta) \geq c + (r - \delta) \sum_i \theta_i \beta_i \mathbb{1}_{\beta_i < \mathbb{B}_P} + f \sum_i \theta_i \mathbb{1}_{\beta_i \in [\mathbb{B}_P, \mathbb{B}];} \quad (13)$$

$$f \geq c + (r - \delta) \sum_i \theta_i \beta_i \mathbb{1}_{\beta_i < \mathbb{B}_P} + f \sum_i \theta_i \mathbb{1}_{\beta_i \in [\mathbb{B}_P, \mathbb{B}].} \quad (14)$$

**Proposition B.2** Under the optimal partially cancelable contract, if the outside option is unattractive ( $r_0 < (1 - \beta_2)r$ ), the supplier receives the full value of TCI if and only if:

$$c \geq \min \left( \frac{\theta_3(\beta_3 - \bar{\beta})}{1 - \bar{\beta}} T, \frac{\theta_1(\beta_2 - \beta_1)}{1 - \beta_2} (T - \gamma^*) - \sum_{i=1}^2 \theta_i \beta_i \gamma^* \right). \quad (15)$$

where  $\gamma^* = r - \frac{r - r_0}{\beta_3} - \frac{l}{1+l} \left[ T - \left( r - \frac{r - r_0}{\beta_3} \right) \right]^+$ .

**Lemma B.2** Under unverifiable information, under any cancelable contract that induces the insurer's monitoring effort, in the resulting PBE,

1. the supplier ships if and only if the insurer does not cancel the contract;
2. if the insurer cancels at information class  $i$ , he also cancels at all information classes  $k > i$ ; and
3. the insurer cancels when the received signal  $i \geq j$  and the supplier ships at  $i < j$  for  $j = 2, 3$  if and only if the contract terms  $(p, \delta, f)$  satisfy the following three conditions jointly:

$$\mathbb{B}_P \in [\beta_{j-1}, \beta_j]; \quad (16)$$

$$\mathbb{B} \geq \frac{\sum_{i \leq j} \theta_i \beta_i}{\sum_{i \leq j} \theta_i}; \quad (17)$$

$$\mathbb{B}_C \leq \frac{\sum_{i > j} \theta_i \beta_i}{\sum_{i > j} \theta_i}; \quad (18)$$

where  $\mathbb{B}()$ ,  $\mathbb{B}_C()$  and  $\mathbb{B}_P()$  are defined in Sections 5 and 6.