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# 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

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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.

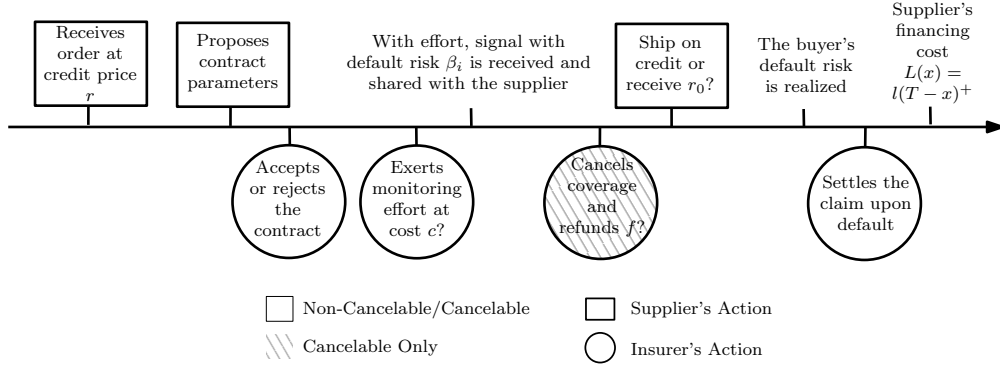
Finally, depending on whether the information obtained is verifiable or not, we consider two scenarios regarding how the insurer shares the information with the supplier. In §5 – 6, we focus on the case when information is verifiable and cannot be strategically manipulated by the insurer. This is largely 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.

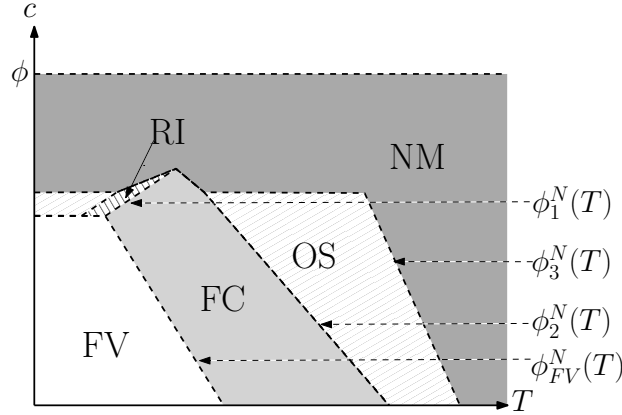
PROPOSITION 2. *When the supplier's outside option is attractive ( $r_0 > (1 - \beta_2)r$ ),*

*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 ( $r_0 < (1 - \beta_2)r$ ),*

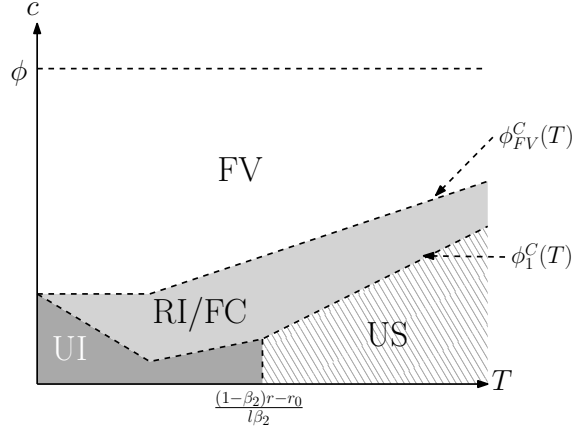
*i) If  $\beta_2 \leq \bar{\beta}$ , there exist threshold functions  $\phi_1^C(T) \leq \phi_{FV}^C(T) = \theta_1(\beta_2 - \beta_1) \max\left(r - \frac{r-r_0}{\beta_3}, \frac{T}{1-\beta_2}\right)$  such that the performance of the optimal cancelable contract is summarized in the following table.*

| 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.

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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 $i = 1, 2, 3$ .<br>$0 \leq \beta_1 < \beta_2 < \beta_3 \leq 1$ |
| $\theta_i$    | 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,<br>$f \in [0, p]$                                     |
| $\phi$        | 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.

# Online Appendix

## Trade Credit Insurance: Operational Value and Contract Choice

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### Appendix C: List of Notation

Table 2 summarizes a list of notation used in this Online Appendix.

**Table 2    Notation**

|           |                                                                                                                                       |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------|
| $\Pi_0$   | $\Pi_0 = (1 - \bar{\beta})r.$                                                                                                         |
| $C_i$     | $C_i = \sum_{j \geq i} \theta_j [r_0 - (1 - \beta_j)r], \text{ for } i \geq 1.$                                                       |
| $\Pi_i$   | $\Pi_i = (1 - \bar{\beta})r + C_i - c, \text{ for } i \geq 1.$                                                                        |
| $C_i^U$   | $C_i^U = \sum_{j \geq i} \theta_j \beta_j \left( r - \frac{r - r_0}{\beta_i} \right).$                                                |
| $\tau_i$  | $\tau_i = (1 - \sum_{j < i} \theta_j \beta_j) \left( r - \frac{r - r_0}{\beta_i} \right).$                                            |
| $l_h$     | $l_h = \frac{\theta_1(\beta_2 - \beta_1)}{(1 - \beta_2) \sum_{i=1}^2 \theta_i \beta_i}.$                                              |
| $\Pi_i^N$ | the payoff under the optimal non-cancelable contract that induces the supplier to ship only at signal $j < i$ .                       |
| $\Pi_i^C$ | the payoff under the optimal cancelable contract under which the insurer cancels at signal $j \geq i$ .                               |
| $\Pi_i^U$ | the payoff under the optimal cancelable contract with unverifiable information under which the insurer cancels at signal $j \geq i$ . |
| $\gamma$  | the amount of coverage that is non-cancelable in a cancelable contract with non-cancelable coverage, $\gamma \in [0, r - \delta]$ .   |

### Appendix D: Proofs

#### D.1. Proofs in Section 4

**Proof of Proposition 1.** To characterize the potential value of trade credit insurance, we first identify the payoffs under two benchmarks: the first-best benchmark and the no-insurance one. Under the first-best benchmark, we consider the following two scenarios depending on whether the insurer exerts monitoring effort.

1. When the insurer does not exert effort, the supplier makes her shipping decision based on the prior expectation of the buyer's default probability  $\bar{\beta}$ . Thus, she ships the order if and only if  $(1 - \bar{\beta})r \geq r_0$ . As this condition always holds under Assumption 1, the supplier always ship and the corresponding payoff is  $(1 - \bar{\beta})r$ .
2. When the insurer exerts effort and hence obtains updated information corresponding to default probability  $\beta_i$ , the supplier ships the order if and only if  $(1 - \beta_i)r \geq r_0$  for  $i = 1, \dots, N$ . The supplier's corresponding payoff is  $(1 - \bar{\beta})r + \sum_i \theta_i [r_0 - (1 - \beta_i)r]^+ - c$ .

By comparing the above two scenarios, we can conclude that exerting effort is beneficial if and only if

$$c \leq \sum_i \theta_i [r_0 - (1 - \beta_i)r]^+ = \phi, \quad (19)$$

and the first-best payoff is therefore:

$$\Pi^{FB} = (1 - \bar{\beta})r + (\phi - c)^+. \quad (20)$$

Next, we consider the no-insurance benchmark. Without insurance, the supplier makes her shipping decision based on the prior expected default risk  $\bar{\beta}$ . If she ships, her expected payoff is  $(1 - \bar{\beta})r - \bar{\beta}L(0)$ . If she does not ship, her payoff is  $r_0$ . Therefore, she ships if and only if  $\Pi^{NI} \geq r_0$ , or equivalently,  $\bar{\beta} \leq \frac{r-r_0}{r+lT}$ . Therefore, the no-insurance payoff is:

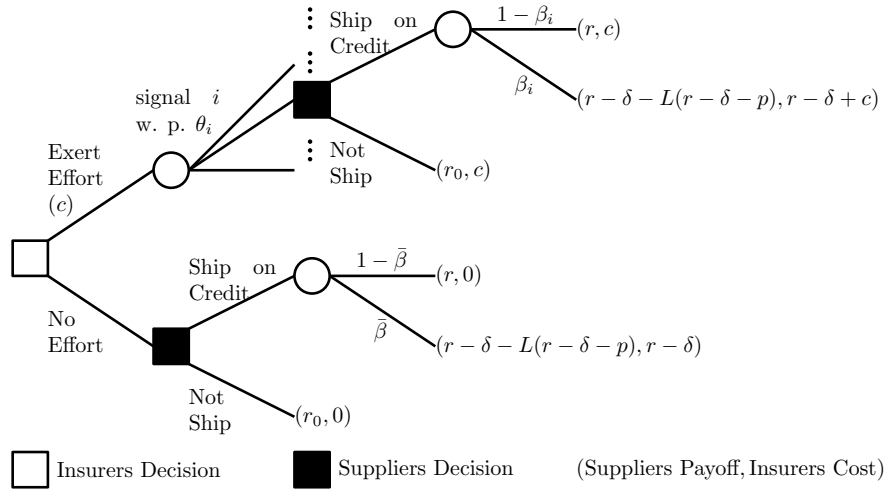
$$\Pi^{NI} = \max((1 - \bar{\beta})r - \bar{\beta}L(0), r_0) = (1 - \bar{\beta})r - \min[\bar{\beta}L(0), (1 - \bar{\beta})r - r_0]. \quad (21)$$

Taking the difference between  $\Pi^{FB}$  and  $\Pi^{NI}$  leads to the potential value of TCI as in the Proposition.  $\square$

## D.2. Proofs in Section 5

**Proof of Lemma 1.** To facilitate the proof, Figure 4 illustrates the extensive form representation of the game between the insurer and the supplier after the two parties have entered the (non-cancelable) contract.

**Figure 4** Extensive form representation of the game between the insurer and the supplier under a non-cancelable contract



For the proof, we first show that all three conditions are necessary for the insurer to exert effort.

1. For (2), we prove it by contradiction. Assume this condition is not satisfied under contract  $(p, \delta)$ , i.e.,  $\mathbb{B} < \bar{\beta}$ . Now we compare the insurer's total costs (effort cost plus claim payout) when he exerts effort (the upper branch in Figure 4) that his cost when he does not exert effort (the lower branch in Figure 4). If the insurer does not exert effort, the supplier's belief on the buyer's default risk remains to be the prior expectation,  $\bar{\beta}$ . By the assumption that  $\mathbb{B} < \bar{\beta}$ , the supplier never ships, and hence the insurer's total cost is zero. On the other hand, if the insurer exerts effort, his total costs is at least  $c$ . By comparing these two costs, we can conclude that under  $\mathbb{B} < \bar{\beta}$ , the insurer does not have the incentive to exert effort. Thus,  $\mathbb{B} \geq \bar{\beta}$  is a necessary condition for the insurer to exert effort.

2. Regarding (3), when (2) is satisfied, i.e., the supplier always ships when she receives no updated information, the insurer's total cost when he does not exert effort is  $\bar{\beta}(r - \delta)$ , the expected claim payout. On the other hand, his total cost with effort is the sum of the effort cost  $c$  and  $(r - \delta) \sum_i \theta_i \beta_i \mathbb{1}_{\beta_i \leq \mathbb{B}}$ , the expected payout under the supplier's optimal shipping decision in response to updated information  $\beta_i$ s, i.e., she ships if and only if  $\beta_i \leq \mathbb{B}$ . By comparing the insurer's total costs between these two scenarios, we can see that the insurer only exerts effort when (3) holds.

3. (4) is the insurer's participation constraint, where the left hand side is the premium charged by the insurer, and the right hand side the total cost with effort, as detailed in the previous discussion on (3). Without this constraint, the premium is not sufficient to compensate the insurer for his total cost, and hence the insurer will not be willing to offer insurance coverage to the supplier at all.

For the sufficient side, similar to the above steps, when all three conditions are satisfied, anticipating the supplier's shipping policy (both with and without updated information), the insurer's total cost under exerting effort is (weakly) lower than his cost without exerting effort, as well as the insurance premium. Therefore, the insurer has the incentive to exert effort.  $\square$

**Proof of Lemma 2.** If a contract does not induce the insurer's monitoring effort, no updated information will be obtained, and hence the supplier makes her shipping decision based on the prior expectation  $\bar{\beta}$ . Following the assumption that  $(1 - \bar{\beta})r > r_0$ , the highest payoff the supplier can achieve under such contract is  $(1 - \bar{\beta})r$ , which can be obtained if and only if no financing cost is incurred and the insurer breaks even.

Next, we will show that contracts that satisfy the following two conditions allows the supplier to achieve this payoff while does not induce insurer's effort.

$$\delta \leq \min \left( \frac{(1 - \bar{\beta})r - T}{1 + \bar{\beta}}, \frac{r - r_0}{\beta_3} \right) \quad (22)$$

$$p = \bar{\beta}(r - \delta) \quad (23)$$

Note that under (22), we have:  $T \leq r - \delta - p$ , which leads to  $L(r - \delta - p) = 0$ . Thus, the supplier does not incur any financing cost when she ships the order. Note that  $\delta \leq \frac{(1 - \bar{\beta})r - T}{1 + \bar{\beta}}$  is also a necessary condition as for  $\delta$  greater than this threshold, the supplier will incur financing cost when she ships, which lowers her payoff under this contract.

Further, (22) also leads to  $\beta_3 \leq \frac{r - r_0}{\delta}$ , that is,  $\mathbb{B} = \beta_3$ , suggesting that the supplier always ships. Substituting  $\mathbb{B} = \beta_3$  into Eq. (3), we can see that for any  $c > 0$  (when  $c = 0$ , the insurer always exerts effort, so it is excluded from this case), Eq. (3) does not hold. Thus, according to Lemma 1, such a contract does not induce insurer effort.

Finally, we note that Eq. (23) ensures that the insurer breaks even. Thus, under the above contract, the supplier's payoff is  $(1 - \bar{\beta})r$ , as desired, and Eq. (22) also imposes an upper bound on  $\delta$ , as stated.  $\square$

**Proof of Proposition 2.** The proof follows three steps.

1. **Step 1.** Define the threshold functions in the proposition that separate the five regions in the proof (full value, financing cost, rent to insurer, over-shipping, and no monitoring).

2. **Step 2.** Summarize the five candidate solutions (contracts) that can be optimal (We show in Lemma E.1 that only these solutions can be optimal).
3. **Step 3.** Compare the five candidate solutions to determine the optimal one.

**Step 1: Define the threshold functions that separate the five regions.** The threshold functions  $\phi_1^N(T)$ ,  $\phi_2^N(T)$ ,  $\phi_3^N(T)$ , and  $\phi_4^N(T)$  that define the boundary of different regions in the Proposition (illustrated in Figure 5) depend on the relative magnitude of  $r_0$  and the following thresholds:

$$R_0^a = \left[ 1 - \frac{\beta_2}{1 + \frac{\theta_1 \beta_1 l}{\theta_2(1+l)}(1 - \theta_1 \beta_1 - \theta_2 \beta_2) \left( \frac{1}{\beta_2} - \frac{1}{\beta_3} \right)} \right] r; \quad (24)$$

$$R_0^c = \left[ 1 - \frac{\beta_2}{1 + \left[ \frac{1 - \theta_1 \beta_1 - \theta_2 \beta_2}{\theta_2} - \frac{1 + (1 - \theta_1 \beta_1)l}{l\beta} \frac{\theta_3 \beta_3}{\theta_2} \right] \left( \frac{1}{\beta_2} - \frac{1}{\beta_3} \right)} \right] r; \quad (25)$$

$$R_0^d = \left[ 1 - \frac{\beta_2}{1 + \left[ \frac{\theta_3 \beta_3}{\theta_2} + \frac{l \sum_{j \geq 2} \theta_j \beta_j}{(1+l)\theta_2} (1 - \theta_1 \beta_1 - \theta_2 \beta_2) \right] \left( \frac{1}{\beta_2} - \frac{1}{\beta_3} \right)} \right] r. \quad (26)$$

1. For  $r_0 \geq R_0^a$ ,

$$\phi_1^N(T) = \min(f_1(T), f_2(T)) \quad (27)$$

$$\phi_2^N(T) = \begin{cases} \min(f_2(T), f_3(T), f_7(T)) & \text{if } r_0 \notin (R_0^c, R_0^d) \\ \min(f_2(T), f_3(T), \max(f_7(T), f_8(T))) & \text{if } r_0 \in (R_0^c, R_0^d) \end{cases} \quad (28)$$

$$\phi_3^N(T) = \phi_4^N(T) = \max(\min(f_2(T), f_3(T)), f_4(T)). \quad (29)$$

2. For  $r_0 < R_0^a$ ,

$$\phi_1^N(T) = \min(f_1(T), f_2(T), f_5(T)); \quad (30)$$

$$\phi_2^N(T) = \min(f_2(T), f_3(T), f_7(T), f_5(T)); \quad (31)$$

$$\phi_3^N(T) = \min(\max(\min(f_2(T), f_3(T)), f_4(T)), f_6(T)); \quad (32)$$

$$\phi_4^N(T) = \max(\min(f_2(T), f_3(T)), f_4(T)). \quad (33)$$

where  $f_1(T) - f_8(T)$  are:

$$f_1(T) = C_2^U + \frac{l \sum_{j \geq 2} \theta_j \beta_j}{1 + (1 - \beta)l} [T - (\tau_2 - C_2^U)]^+; \quad (34)$$

$$f_2(T) = C_2 - \frac{l \sum_{j < 2} \theta_j \beta_j}{1 + l} [T - (\tau_2 - C_2)]; \quad (35)$$

$$f_3(T) = C_2^U + \frac{l \sum_{j \geq 2} \theta_j \beta_j}{1 + l} [T - (\tau_2 - C_2)]^+; \quad (36)$$

$$f_4(T) = C_3 - \frac{l \sum_{j < 3} \theta_j \beta_j}{1 + l} [T - (\tau_3 - C_3)]^+; \quad (37)$$

$$f_5(T) = \left( 1 - \theta_1 \beta_1 - \theta_2 \beta_2 + \frac{\theta_2 \beta_2 (1 + l)}{\theta_1 \beta_1 l} \right) \left( r - \frac{r - r_0}{\beta_2} \right) - T; \quad (38)$$

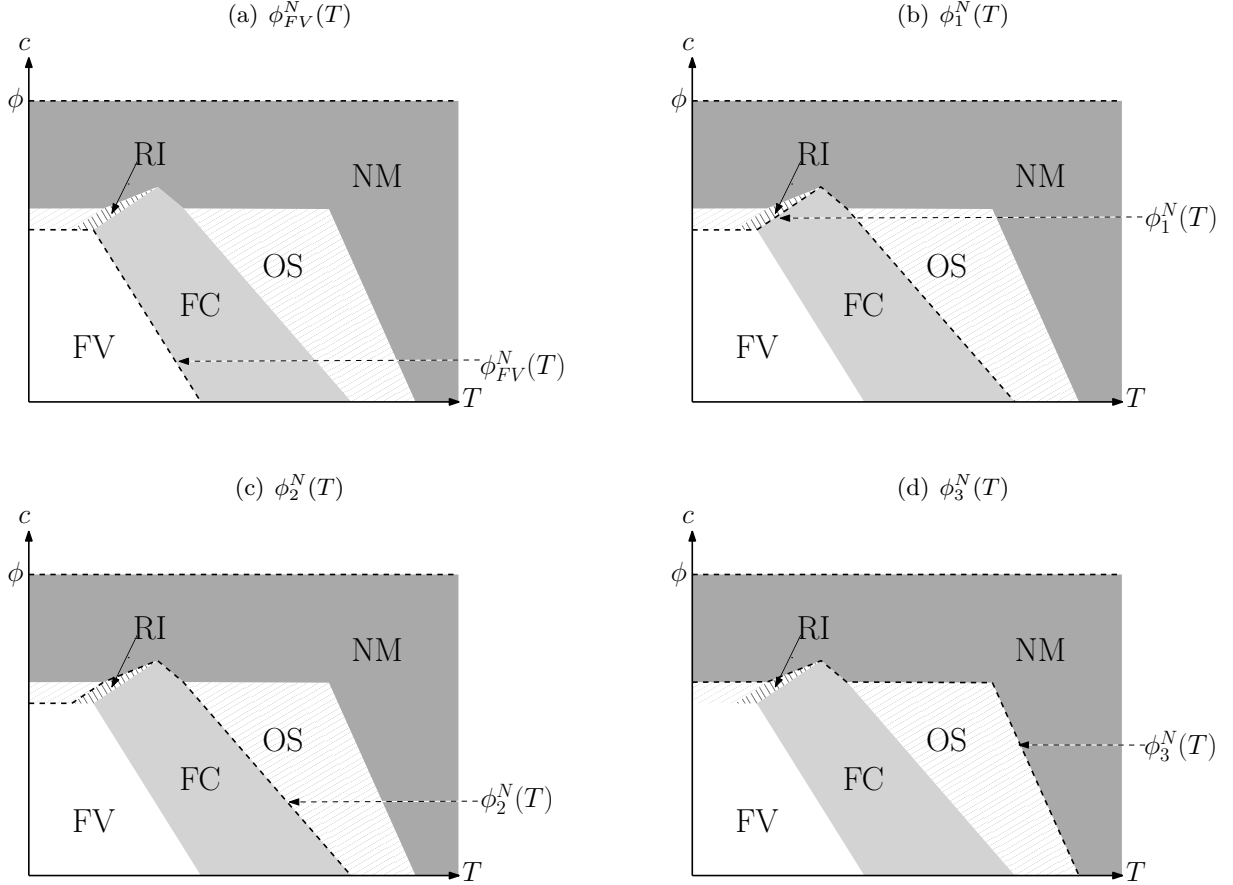
$$f_6(T) = \frac{\frac{l(\theta_1 \beta_1 + \theta_2 \beta_2)}{1 + l(1 - \theta_1 \beta_1 - \theta_2 \beta_2)} \tau_3 - \frac{l \theta_1 \beta_1}{1 + l(1 - \theta_1 \beta_1)} \tau_2 - \theta_2 \beta_2 \left( r - \frac{r - r_0}{\beta_2} \right)}{\frac{l(\theta_1 \beta_1 + \theta_2 \beta_2)}{1 + l(1 - \theta_1 \beta_1 - \theta_2 \beta_2)} - \frac{l \theta_1 \beta_1}{1 + l(1 - \theta_1 \beta_1)}} - T; \quad (39)$$

$$f_7(T) = C_2^U + \frac{l \sum_{j \geq 2} \theta_j \beta_j}{1 + \theta_1 \beta_1 + (1 - \beta)l} \left[ T - (1 - \theta_1 \beta_1 - \theta_3 \beta_3) \left( r - \frac{r - r_0}{\beta_2} \right) \right]^+; \quad (40)$$

$$f_8(T) = C_2^U + \frac{T - (1 - \theta_1 \beta_1 - \theta_3 \beta_3) \left( r - \frac{r - r_0}{\beta_2} \right) + \frac{l \sum_{j < 3} \theta_j \beta_j}{1 + l(1 - \sum_{j < 3} \theta_j \beta_j)} (T - \tau_3 + C_2^U)}{\frac{1 + \theta_1 \beta_1 + (1 - \beta)l}{l \sum_{j \geq 2} \theta_j \beta_j} - \frac{l \sum_{j < 3} \theta_j \beta_j}{1 + l(1 - \sum_{j < 3} \theta_j \beta_j)}}. \quad (41)$$

According to the definitions of  $\phi_i^N()$  and  $f_i()$ , it is easy to verify that  $\phi_{FV}^N(T) \leq \phi_1^N(T) \leq \phi_2^N(T) \leq \phi_3^N(T) \leq \phi_4^N(T)$ . For example,  $\phi_1^N(T) \leq \phi_2^N(T)$  because  $\min(f_3(T), f_7(T)) > f_1(T)$ .

**Figure 5** Threshold functions in Proposition 2.



Notes. The above threshold functions are drawn for the case  $r_0 \geq R_0^a$ , where  $\phi_3^N(T) = \phi_4^N(T)$ .

**Step 2: Summarize the five candidate solutions.** In Lemma E.1, we characterize the optimal one among all non-cancelable contracts that induce a given shipping policy (e.g., the supplier ships at  $i = 1$ , but not at  $i = 2, 3$ ). By enumerating these solutions across all possible shipping policies, we identify five candidate non-cancelable contracts: Full Value (FV), Financing Cost (FC), Rent to Insurer (RI), Over-shipping (OS), and No Monitoring (NM).<sup>7</sup> By Lemma E.1 and Lemma 2, the optimal non-cancelable contract can only be

<sup>7</sup> Note that the five candidate solutions to the optimal non-cancelable contracts bearing the same name with the five regions in the Proposition. As shown later, the solution will be the optimal one in the region that bears the same name. For example, Region *FV* is defined by the range of  $c$  where Solution *FV* defined below is optimal.

chosen from these five candidates. In the following, we summarize the contract term and basic properties of these five candidates.

1. Solution *FV*: This represents the solution that the supplier receives the full value of TCI, i.e., her payoff under the contract is  $\Pi^{FB} = \theta_1(1 - \beta_1)r + (\theta_2 + \theta_3)r_0 - c$ . To achieve this payoff, the contract must satisfy three conditions: 1) the shipping policy is efficiency (ships at  $i = 1$ , but not at  $i = 2, 3$ ), the supplier By examining the candidate solutions in Lemma E.1 and Lemma 2, we note that this payoff can be achieved under the following contract:

$$\delta = \frac{r - r_0}{\beta_2} - \frac{l(T + c - \tau_2)^+}{1 + l(1 - \theta_1\beta_1)}, \quad p = c + \theta_1\beta_1(r - \delta). \quad (42)$$

This contract corresponds to Statement 1 in Lemma E.1 (Eq. (123)) with  $i = 2$ . Under this contract, the supplier's payoff follows  $\Pi_2^{NB}$  from Eq. (124), which equals to  $\Pi^{FB}$  if and only if  $c \leq \phi_{FV}^N(T)$ , where  $\phi_{FV}^N(T)$  is defined in the Proposition.

2. Solution *FC*: This represents the solution that the supplier ships efficiently, i.e., only ships at  $i = 1$ , and she incurs financing cost, but does not surrender rent to the insurer. This corresponds to Statement 1 in Lemma E.1 with  $i = 2$  when  $c > \phi_{FV}^N(T)$ , that is

$$\delta = \frac{r - r_0}{\beta_2} - \frac{l(T + c - \tau_2)^+}{1 + l(1 - \theta_1\beta_1)}, \quad p = c + \theta_1\beta_1(r - \delta). \quad (43)$$

In this case, the insurer's participation constraint is binding, and the supplier's payoff is

$$\Pi_2^{NB} = \Pi_2 - \frac{l \sum_{j < 2} \theta_j \beta_j}{1 + l(1 - \sum_{j < 2} \theta_j \beta_j)} (T + c - \tau_2)^+. \quad (44)$$

When  $c > \phi_{FV}^N(T)$ ,  $\Pi_2^{NB} < \Pi_2$ , and the difference is due to the financing cost incurred. In addition, according to Lemma E.1, this solution is optimal only if  $c < \min(f_1(T), f_2(T))$  (when it is feasible and dominates the contract without effort  $\Pi_0$ ).

3. Solution *RI*: This represents the solution that the supplier ships at  $i = 1$ , and she surrenders rent to the insurer. This corresponds to Statement 2 in Lemma E.1 with  $i = 2$ , that is,

$$\delta = r - \frac{c}{\sum_{j \geq 2} \theta_j \beta_j}, \quad p = \frac{1}{l} \left( \frac{r - r_0}{\beta_2} - r \right) + \left( 1 + \frac{1}{l} \right) \frac{c}{\sum_{j \geq 2} \theta_j \beta_j} - T. \quad (45)$$

as shown in Lemma E.1, the insurer's participation constraint is not binding, and the supplier's payoff follows:

$$\Pi_2^{NN} = \Pi_2 - \left[ \frac{(1 - \bar{\beta})lc + (1 + \sum_{j < 2} \theta_j \beta_j l)(c - C_2^U)}{l \sum_{j \geq 2} \theta_j \beta_j} - T \right]. \quad (46)$$

as given by Eq. (126) in Lemma E.1. By Lemma E.1, this solution can be optimal only if  $c \in (f_1(T), f_3(T)]$  (when it is feasible and dominates  $\Pi_0$ ).

4. Solution *OS*: This represents the solution that the supplier ships at  $i = 1, 2$ , i.e., she over-ships. This corresponds to Statement 1 in Lemma E.1 with  $i = 3$ , that is,

$$\delta = \frac{r - r_0}{\beta_3} - \frac{l(T + c - \tau_3)^+}{1 + l(1 - \theta_1\beta_1 - \theta_2\beta_2)}, \quad p = c + (\theta_1\beta_1 + \theta_2\beta_2)(r - \delta). \quad (47)$$

Under this contract, the insurer's participation constraint is binding, and the supplier's payoff is

$$\Pi_3^{NB} = \Pi_3 - \frac{l \sum_{j < 3} \theta_j \beta_j}{1 + l(1 - \sum_{j < 3} \theta_j \beta_j)} (T + c - \tau_3)^+. \quad (48)$$

as given by Eq. (124) in Lemma E.1. We can show that follows  $\Pi_3^{NB} \leq \Pi_3 < \Pi_2$ . This solution can be optimal only if  $c \leq f_4(T)$  (when it is feasible and dominates  $\Pi_0$ ).

5. Solution *NM*: This represents the solution that the insurer does not exert effort, and the supplier ships at  $i = 1, 2, 3$ . The supplier's payoff  $\Pi_0$  as given by Lemma 2, and the insurer's participation constraint is binding. Also according to the second part of Lemma E.1, this solution is optimal if and only if  $c \geq \phi_4^N(T) = \max(\min(f_2(T), f_3(T)), f_4(T))$ , when it dominates  $\Pi_2^{NB}$ ,  $\Pi_2^{NN}$  and  $\Pi_3^{NB}$ .

**Step 3: Compare the candidate solutions and determine the optimal one.** From the above summary of the candidate solutions, we have identified the boundary of Region *FV* and that of Region *NM*. In the following, we prove the boundaries of Region *FC*, *RI*, and *OS* are  $\phi_1^N()$  (between *FC* and *RI*),  $\phi_2^N()$  (between *RI* and *OS*), and  $\phi_3^N()$  (between *OS* and *FC*), as defined above. To do so, we note that the regions that Solution *FC* and Solution *RI* can be optimal are mutually exclusive, and thus it is not necessary to compare these two solutions. Therefore, we only need to compare the following two pairs.

1. The comparison between Solution *FC* ( $\Pi_2^{NB}$ ) and Solution *OS* ( $\Pi_3^{NB}$ ) over the region that both can be optimal, i.e.,  $c \in (\phi_{FV}^N(T), \min(f_1(T), f_2(T), f_4(T))]$ .
2. The comparison between Solution *RI* ( $\Pi_2^{NN}$ ) and Solution *OS* ( $\Pi_3^{NB}$ ) over the region that both can be optimal,  $c \in (f_1(T), \min(f_3(T), f_4(T))]$ .

We make these comparisons according to the relative magnitude between  $r_0$  and  $R_0^a$ .

1. When  $r_0 \geq R_0^a$ , between Solution *FC* and Solution *OS*, we can verify that when  $c \in (\phi_{FV}^N(T), \min(f_1(T), f_2(T), f_4(T))]$ ,  $\Pi_2^{NB} \geq \Pi_3^{NB}$ . Thus, the *FC* region, where Solution *FC* is optimal, is defined as  $c \in (\phi_{FV}^N(T), \phi_1^N(T)]$ , where  $\phi_1^N(T) = \min(f_1(T), f_2(T))$ , and  $\phi_3^N(T) = \phi_4^N(T)$ . To further determine  $\phi_2^N(T)$ , we compare Solution *RI* and Solution *OS* by the following scenarios:
  - (a) When  $r_0 \geq \left[1 - \frac{\beta_2}{1 + \frac{\theta_3 \beta_3}{\theta_2} \left(\frac{1}{\beta_2} - \frac{1}{\beta_3}\right)}\right] r := R_0^b$ , we can verify that the region where Solution *OS* can be optimal, i.e.,  $c \leq f_4(T)$  and the region that Solution *RI* can be optimal, i.e.,  $c \in (f_1(T), f_3(T))$ , do not overlap. Thus,  $\phi_2^N(T) = \min(f_2(T), f_3(T))$  as  $f_7(T) > f_3(T)$  over the relevant range.
  - (b) When  $r_0 < R_0^b$ , and  $r_0 \notin (R_0^c, R_0^d)$ , in the region where both Solution *OS* and Solution *RI* could be optimal, i.e.,  $c \leq (f_1(T), \min(f_3(T), f_4(T)))$ , as  $\Pi_3^{NB} = \Pi_3$ , we have that  $\Pi_3^{NB} > \Pi_2^{NN}$  if and only if  $c > f_7(T)$ . Thus,  $\phi_2^N(T) = \min(f_2(T), f_3(T), f_7(T))$ .
  - (c) When  $r_0 < R_0^b$  and  $r_0 \in (R_0^c, R_0^d)$ , in the region where both Solution *OS* and Solution *RI* can be optimal, i.e.,  $c \leq (f_1(T), \min(f_3(T), f_4(T)))$ , we can verify that in the region when  $\Pi_3^{NB} = \Pi_3$ , we have  $\Pi_3^{NB} > \Pi_2^{NN}$  if and only if  $c > f_7(T)$ ; and in the region when  $\Pi_3^{NB} < \Pi_3$ ,  $\Pi_3^{NB} > \Pi_2^{NN}$  if and only if  $c > f_8(T)$ . Thus,  $\phi_2^N(T) = \min(f_2(T), f_3(T), \max(f_7(T), f_8(T)))$ .
2. When  $r_0 < R_0^a$ , between Solution *FC* and Solution *OS*, we can verify that when  $c \in (\phi_{FV}^N(T), \min(f_1(T), f_2(T), f_4(T))]$ ,  $\Pi_3^{NB} > \Pi_2^{NB}$  if and only if  $c \in (f_5(T), \min(f_2(T), f_6(T)))$ . Thus, Solution *FC* is optimal when  $c \in (\phi_{FV}^N(T), \phi_1^N(T))$  or  $c \in (\phi_3^N(T), \phi_4^N(T))$  where  $\phi_1^N(T)$ ,  $\phi_3^N(T)$ , and

$\phi_4^N(T)$  are defined as above. Next, between Solution *RI* and Solution *OS*, the result is similar to the case with  $r_0 \geq R_0^a$ . Taking into consideration of the definition of  $\phi_1^N(T)$ , we have that  $\phi_2^N(T) = \min(f_2(T), f_3(T), f_7(T), f_5(T))$ .  $\square$

**Proof of Proposition B.1.** Analogous to the proof of Proposition 2, this proof consists of the following three steps.

1. **Step 1.** Define the threshold functions in the proposition that separate the four regions (full value, financing cost, under-shipping, and no monitoring).
2. **Step 2.** Summarize the four candidate solutions (contracts) that can be optimal (We show in Lemma E.1 that only these solutions can be optimal).
3. **Step 3.** Compare the candidate solutions to determine the optimal one.

**Step 1. Define the threshold functions that separate the four regions.** The definition of the threshold functions  $\phi_1^{NL}(T)$ ,  $\phi_2^{NL}(T)$ , and  $\phi_3^{NL}(T)$  depending on the relative magnitude of  $r_0$  and the following thresholds:

$$R_0^e := \left[ 1 - \frac{\bar{\beta}}{1 - \theta_1 \left( 1 - \frac{\beta_1}{\beta_2} \right) + \frac{l \sum_{j < 3} \theta_j \beta_j}{1+l} (1 - \sum_{j < 3} \theta_j \beta_j) \frac{\theta_1 \beta_1}{\theta_2 \beta_2} \left( \frac{1}{\beta_2} - \frac{1}{\beta_3} \right)} \right] r; \quad (49)$$

$$R_0^f := \left[ 1 - \frac{\beta_2}{1 - \frac{\theta_3(\beta_3 - \beta_2)}{\bar{\beta}} + \frac{l \sum_{j < 3} \theta_j \beta_j}{(1+l)\theta_2} (1 - \theta_1 \beta_1 - \theta_2 \beta_2) \left( \frac{1}{\beta_2} - \frac{1}{\beta_3} \right)} \right] r. \quad (50)$$

With these definitions, as well as  $f_1() - f_8()$  defined in the proof of Proposition 2, we define  $\phi_1^{NL}$ ,  $\phi_2^{NL}(T)$ , and  $\phi_3^{NL}(T)$  as follows.

1. For  $\beta_2 \leq \bar{\beta}$  or  $r_0 \leq R_0^e$ ,

$$\phi_1^{NL}(T) = \phi_2^{NL}(T) = \phi_3^{NL}(T) = f_4(T). \quad (51)$$

2. For  $\beta_2 > \bar{\beta}$  and  $r_0 \in (R_0^e, R_0^f]$ ,

$$\phi_1^{NL}(T) = \min(f_4(T), f_6(T)); \quad (52)$$

$$\phi_2^{NL}(T) = \phi_3^{NL}(T) = \max(f_2(T), f_4(T)). \quad (53)$$

3. For  $\beta_2 > \bar{\beta}$  and  $r_0 > R_0^f$ ,

$$\phi_1^{NL}(T) = \phi_{FV}^{NL}(T); \quad (54)$$

$$\phi_2^{NL}(T) = \max(\phi_{FV}^{NL}(T), \min(f_2(T), f_3(T), f_8(T))); \quad (55)$$

$$\phi_3^{NL}(T) = \max(f_4(T), \min(f_2(T), f_3(T))). \quad (56)$$

According to the definition of  $\phi_{FV}^{NL}(T)$ ,  $\phi_1^{NL}(T)$ ,  $\phi_2^{NL}(T)$ , and  $\phi_3^{NL}(T)$ , we can verify that  $\phi_{FV}^{NL}(T) \leq \phi_1^{NL}(T) \leq \phi_2^{NL}(T) \leq \phi_3^{NL}(T)$ .

**Step 2. Summarize the four candidate solutions.** We define the four candidate solutions of the optimal non-cancelable contracts that corresponds to the region with the same name in the Proposition. The candidate solutions are characterized in Lemma E.1 and Lemma 2.

1. Solution  $FV$ : This represents the solution that the supplier receives the full value of TCI, i.e., her payoff is  $\Pi_3$ . By examining the candidate solutions in Lemma E.1 and Lemma 2, we note that this payoff is achieved if and only if Statement 1 in Lemma E.1 with  $i = 3$  is the relevant solution, that is,

$$\delta = \frac{r - r_0}{\beta_3} - \frac{l(T + c - \tau_3)^+}{1 + l(1 - \theta_1\beta_1 - \theta_2\beta_2)}, \quad p = c + (\theta_1\beta_1 + \theta_2\beta_2)(r - \delta). \quad (57)$$

In this case, the supplier's payoff follows  $\Pi_3^{NB}$  as in Eq. (124), and it equals to  $\Pi^{FB}$  if and only if  $c \leq \phi_{FV}^{NL}(T)$  where  $\phi_{FV}^{NL}(T)$  is defined in the Proposition.

2. Solution  $FC$ : This represents the solution that the supplier ships efficiently, i.e., ships at  $i = 1, 2$ , and she incurs financing cost, but does not surrender rent to the insurer. This corresponds to Statement 1 in Lemma E.1 with  $i = 3$  (as in the FV scenario) when  $c > \phi_{FV}^{NL}(T)$ . In this case, the supplier's payoff  $\Pi_3^{NB} < \Pi_3$ . In addition, according to Lemma E.1, this solution is optimal only if  $c \in (\phi_{FV}^{NL}(T), f_4(T)]$  (when it is feasible and dominates the contract without effort  $\Pi_0$ ).
3. Solution  $US$ : This represents the solution that the supplier ships only at  $i = 1$ , i.e., she under-ships. This corresponds to Statements 1 or 2 in Lemma E.1 with  $i = 2$ , and  $\Pi_2^{NB}$  or  $\Pi_2^{NN}$ , both of which are smaller than  $\Pi_3$ . This solution can be optimal only if  $\beta_2 > \bar{\beta}$  and  $c < \min(f_2(T), f_3(T))$  (when it dominates  $\Pi_0$ ).
4. Solution  $NM$ : This represents the solution that the insurer does not exert effort, and the supplier ships at  $i = 1, 2, 3$ . The supplier's payoff  $\Pi_0$  as given by Lemma 2. Also according to Lemma 2 (the second part), this solution is optimal if and only if  $c \geq \phi_3^{NL}(T) = \max(\min(f_2(T), f_3(T)), f_4(T))$ , when it dominates  $FV$ ,  $FC$ , and  $US$ .

**Step 3. Compare the candidate solutions and determine the optimal one.** Based on the above definition of the solution regions, we have identified the boundary of Region  $FV$  and that of Region  $NM$ . In the following, we prove the boundaries of Regions  $FC$  and  $US$  as in the Proposition. First, we note Solution  $US$  is not relevant when  $\beta_2 \leq \bar{\beta}$ . Thus, in this region, we have  $\phi_1^{NL}(T) = \phi_2^{NL}(T) = \phi_3^{NL}(T) = f_4(T)$ .

For the case with  $\beta_2 > \bar{\beta}$ , and further consider the following three scenarios:

1. When  $r_0 \leq R_0^e$ , we can verify that  $\Pi_3^{NB} \geq \max(\Pi_2^{NN}, \Pi_2^{NB})$  over the region that Solution  $FC$  and  $US$  co-exist. Thus, Solution  $US$  is never optimal, and we have  $\phi_1^{NL}(T) = \phi_2^{NL}(T) = \phi_3^{NL}(T) = f_4(T)$ .
2. When  $r_0 \in (R_0^e, R_0^f)$ , we can show that over the region that  $\Pi_3^{NB}$  and  $\Pi_2^{NN}$  co-exist,  $\Pi_3^{NB} \geq \Pi_2^{NN}$ . However, over the region that  $\Pi_3^{NB}$  and  $\Pi_2^{NB}$  co-exist,  $\Pi_3^{NB} \geq \Pi_2^{NB}$  if and only if  $c \leq f_6(T)$ , thus,  $\phi_1^{NL}(T) = \min(f_4(T), f_6(T))$ , and  $\phi_2^{NL}(T) = \phi_3^{NL}(T) = \max(f_2(T), f_4(T))$ .
3. When  $r_0 > R_0^f$ , we can show that over the region that  $\Pi_3^{NB}$  and  $\Pi_2^{NB}$  co-exist,  $\Pi_3^{NB} \leq \Pi_2^{NB}$ . However, over the region that  $\Pi_3^{NB}$  and  $\Pi_2^{NN}$  co-exist,  $\Pi_3^{NB} \geq \Pi_2^{NN}$  if and only if  $c \geq f_8(T)$ . Thus, we have  $\phi_1^{NL}(T) = \phi_{FV}^{NL}(T)$ ,  $\phi_2^{NL}(T) = \max(\phi_{FV}^{NL}(T), \min(f_2(T), f_3(T), f_8(T)))$ , and  $\phi_3^{NL}(T) = \max(f_4(T), \min(f_2(T), f_3(T)))$ .  $\square$

### D.3. Proofs in Section 6

**Proof of Lemma 3.** We prove  $\mathbb{B} > \mathbb{B}_C$  by contradiction. Suppose  $\mathbb{B} \leq \mathbb{B}_C$ . By the definition of  $\mathbb{B}$  and  $\mathbb{B}_C$ , this condition is equivalent to:

$$r + L(f - p) \leq \delta + L(r - p - \delta) \quad (58)$$

By the definition of deductible, we must have  $\delta \leq r$ . Therefore, for (58) to hold, we must have  $L(r - p - \delta) \geq L(f - p)$ , or equivalently,

$$r - \delta \leq f, \quad (59)$$

for  $L(x)$  weakly decreases in  $x$ . By the definition of  $\mathbb{B}_P$  in (7), (59) is equivalent to  $\mathbb{B}_P \geq 1$ , which suggests that the insurer never cancels at any signal, contradicts with the condition that the insurer cancels coverage at certain signals, as stated in the Lemma. Therefore, we must have  $\mathbb{B} > \mathbb{B}_C$ .

Similarly, we can prove that  $\mathbb{B} > \mathbb{B}_P$ . To see this, note that the insurer only cancels when  $\beta_i \in [\mathbb{B}_P, \mathbb{B}]$ . If  $\mathbb{B} \leq \mathbb{B}_P$ , the insurer never cancels, which again contradicts with the condition that the insurer cancels coverage at certain signals.

Combining the above two results, we have that  $\mathbb{B} > \max(\mathbb{B}_C, \mathbb{B}_P)$ . Given this result, we next prove the supplier's shipping policy by considering the following four ranges for  $\beta_i$ .

1. for  $\beta_i < \mathbb{B}_P$ , as  $\mathbb{B}_P < \mathbb{B}$ , the insurer knows that if he does not cancel the coverage, the supplier ships the order. Even though, in this region, his cost of canceling the contract (the refund  $f$ ) is greater than the expected claim payout,  $\beta_i(r - \delta)$  for  $\beta_i < \mathbb{B}_P = \frac{f}{r - \delta}$ . Therefore, in this region, the insurer does not cancel, and hence the supplier ships.
2. for  $\beta_i \in [\mathbb{B}_P, \max(\mathbb{B}_C, \mathbb{B}_P))$ , we further consider two cases,
  - (a) if  $\mathbb{B}_C < \mathbb{B}_P$ ,  $\max(\mathbb{B}_C, \mathbb{B}_P) = \mathbb{B}_P$ , and hence  $[\mathbb{B}_P, \max(\mathbb{B}_C, \mathbb{B}_P)) = \emptyset$ , and the two parties' policies are thereby irrelevant.
  - (b) if  $\mathbb{B}_C \geq \mathbb{B}_P$ , the above region becomes  $\beta_i \in [\mathbb{B}_P, \mathbb{B}_C)$ . Similar to Case 1 ( $\beta_i < \mathbb{B}_P$ ), as  $\mathbb{B} > \max(\mathbb{B}_P, \mathbb{B}_C)$ , the insurer knows that if he does not cancel, the supplier ships the order. However, different from Case 1, the insurer's cost of cancelation (refund  $f$ ) is smaller than the expected payout,  $\beta_i(r - \delta^C)$  in this region, and hence the insurer cancels. For the supplier, knowing that the insurer will cancel, her payoff under not shipping,  $r_0$ , is smaller than her expected payoff under shipping,  $(1 - \beta_i)r - L(f - p)$  for  $\beta_i < \mathbb{B}_C = \frac{r - r_0}{r + L(f - p)}$ . Therefore, the supplier still ships even when the insurer cancels her coverage.
3. for  $\beta_i \in [\max(\mathbb{B}_C, \mathbb{B}_P), \mathbb{B}]$ , similar as Case 2(b), the insurer knows that if he does not cancel the coverage, the supplier ships. As such, he cancels the coverage as his cost of doing so ( $f$ ) is less than the alternative  $\beta_i(r - \delta)$ . For the supplier, however, observing that her coverage is canceled, the supplier's payoff under not shipping,  $r_0$ , dominates that under shipping,  $r - L(f - p)$ , because  $\beta_i \geq \mathbb{B}_C$ . Therefore, she does not ship the order.

4. for  $\beta_i > \mathbb{B}$ , by the definition of  $\mathbb{B}$ , the insurer knows that even if he does not cancel the insurer's coverage, the supplier still does not ship. As such, the insurer's cost under not canceling is zero, lowering than his cost by canceling the coverage ( $f$ ). Therefore, he does not cancel the coverage. For the supplier, even if the insurer does not cancel, she still not ship because her payoff under shipping is lower than  $r_0$ .

Summarizing the supplier's shipping policy over these four regions, the supplier ships if and only if  $\beta_i \leq \max(\mathbb{B}_C, \mathbb{B}_P)$ , as stated in the Lemma.  $\square$

**Proof of Lemma B.1.** Similar to the proof of Lemma 1, we first show that (12) – (14) are necessary for the insurer to exert effort.

First, note that (12) is analogous to (2), and it states that under the contract, if the insurer does not exert effort, the supplier ships under on the prior expectation  $\bar{\beta}$ .

Next, note that the right hand sides of (13) – (14) are identical, which equal to the insurer's total cost if he exerts effort. The cost consists of three parts: the effort cost  $c$ , the insurer's expected payout when the insurer does not cancel *and* the supplier ships,  $(r - \delta) \sum_i \theta_i \beta_i \mathbb{1}_{\beta_i < \mathbb{B}_P}$ , and the refund the insurer has to pay when he cancels the coverage,  $f \sum_i \theta_i \mathbb{1}_{\beta_i \in [\mathbb{B}_P, \mathbb{B}]}$ . For the insurer to exert effort, his total cost of doing so must be (weakly) lower than his other two options, corresponding the left hand side of (13) – (14), respectively:

1. (13) states that it is better off for the insurer to exert effort than participating the contract, but does not exert effort and never cancels, under which his cost is the expected payout under the prior expectation  $\bar{\beta}$  as the supplier always ships, according to (12).
2. (14) states that it is better off for the insurer to exert effort than participating the contract, but does not exert effort and always cancels, under which his cost is the refund  $f$ .

In addition, note that as  $f \leq p$ , (14) also guarantees it is better off for the insurer to exert effort than not participating the contract, in which case he does not receive the premium  $p$ .

For the sufficient side, similar to the proof in Lemma 1, we can see that when all four conditions are satisfied, anticipating the supplier's shipping decision and his own cancelation decision, the insurer's total cost under exerting effort is (weakly) lower than all of his other options. Therefore, the four conditions are sufficient to ensure him to exert monitoring effort.  $\square$

**Proof of Proposition 3.** To show that the proposed contract ( $\delta = 0$ , and  $p = f = \frac{c}{\theta_1} + \beta_1 r$ ) is optimal and allows the supplier to receive the full value of TCI for  $r_0 \geq (1 - \beta_2)r$ , it is necessary and sufficient to show that the supplier's payoff under such contract is  $\Pi_2 = \theta_1(1 - \beta_1)r + \sum_{i=2}^3 \theta_i r_0 - c$ , which is the highest possible supplier payoff under  $r_0 \geq (1 - \beta_2)r$ . To show that, we following the following three steps.

First, we note that this payoff can only be achieved when both the insurer's cancelation policy and the supplier's shipping policy are efficient, that is, the insurer cancels at  $i = 2, 3$  and the supplier only ships at  $i = 1$ . By Lemma E.2, the optimal contract under such policies are the solution of the following optimization problem:

$$\max_{p, \delta \in [0, r], f \leq p} -p + \theta_1[r - \beta_1(\delta + L(r - p - \delta))] + (r_0 + f) \sum_{i=2}^3 \theta_i; \quad (60)$$

$$r_0 \leq r - \bar{\beta}[r + L(r - \delta - p)]; \quad (61)$$

$$\bar{\beta}(r - \delta) \geq c + \theta_1\beta_1(r - \delta) + (\theta_2 + \theta_3)f; \quad (62)$$

$$f \geq c + \theta_1\beta_1(r - \delta) + (\theta_2 + \theta_3)f; \quad (63)$$

$$f \geq \beta_1(r - \delta); \quad (64)$$

$$f < \beta_2(r - \delta); \quad (65)$$

$$r_0 \geq r - \beta_2[r + L(f - p)]; \quad (66)$$

$$r_0 < r - \beta_3L(r - \delta - p). \quad (67)$$

Specifically, Eq. (60) is the supplier's payoff (without effort cost) under the specified policy. Following Lemma B.1, (61) – (63) jointly ensure the insurer to exert effort under such policies. (64) – (65) states that the insurer cancels at  $i = 2$ , but not  $i = 1$ . (66) ensures that the supplier does not ship when the insurer cancels at  $i = 2$ , and finally, (67) says that if insurer does not cancel at  $i = 3$ , the supplier would have shipped at that scenario. Thus, jointly, (64) – (67) guarantees that with updated information, the insurer cancels at  $i = 2, 3$  and the supplier ships only at  $i = 1$ .

Second, we verify that the contract stated in the proposition ( $\delta = 0$ , and  $p = f = \frac{c}{\theta_1} + \beta_1 r$ ) is a feasible solution to the above optimization problem. To show that, first note that at  $\delta = 0$ , according to Assumption 2, we have  $L(r - \delta - p) = 0$ . Next, under the assumption that  $r_0 \leq (1 - \bar{\beta})r$ , (61) holds. In addition, we substitute  $f$  and  $\delta$  into (61), which becomes  $c \leq \theta_1 [\theta_2\beta_2 + \theta_3\beta_3 - (\theta_2 + \theta_3)\beta_1]r$ , or equivalently,  $c \leq [\theta_2(\beta_2 - \bar{\beta}) + \theta_3(\beta_3 - \bar{\beta})]r$ . As  $r_0 < (1 - \bar{\beta})r$ , the above equation always holds for  $c \leq \phi = \sum_{i=2}^3 \theta_i[r_0 - (1 - \beta_i)r]$ , the region that we are interested in. Similarly, it is easy to show that (63) – (65) and (67) are all satisfied when substituting  $\delta = 0$  and  $f = \frac{c}{\theta_1} + \beta_1 r$ . Finally, as  $r_0 \geq (1 - \beta_2)r$  and  $L(f - p) = L(0) \geq 0$ , (66) is also satisfied. Combined, the proposed contract is a feasible solution to the optimization problem.

At last, by substituting the contract into (60), we note that the above contract leads to the highest possible supplier payoff  $\Pi_2$ . Thus, the above contract is optimal.  $\square$

**Proof of Proposition 4.** When  $r_0 < (1 - \beta_2)r$ , to identify the optimal contract, we first specify all possible scenarios in terms of the insurer's cancellation policy; for each scenario, we either identify the optimal cancelable contract, or show that any cancelable contract under that scenario will be (weakly) dominated by contracts in other scenarios. By enumerating all possible combinations of the insurer's cancellation policy, we find it is sufficient to consider only the following two cases.

1. The insurer cancels at  $i = 2, 3$ . The optimal contract in this scenario is summarized in Lemma E.3, that is,

$$\delta = 0; \quad p = f = \frac{c}{\theta_1} + \beta_1 r. \quad (68)$$

We refer to the solution in this scenario *Solution C.2* (cancels at  $i = 2$  and above). Under this solution, the insurance premium equals to the insurer's expected cost, thus, the insurer does not extract any rent. However, the supplier faces the problem of over-cancellation, i.e., the insurer cancels at  $i = 2$  even if it is efficient to ship at  $i = 2$ . Further, depending on the supplier's financial constraint  $T$ , the supplier's payoff and shipping decision under the optimal contract can be discussed in two cases.

- (a) When  $T \leq \frac{(1-\beta_2)r-r_0}{l\beta_2}$ , the supplier ships at  $i = 1, 2$ . That is, the shipping policy is efficient. However, the supplier is not insured when she ships at  $i = 2$ . Therefore, the supplier incurs financing cost.
- (b) When  $T > \frac{(1-\beta_2)r-r_0}{l\beta_2}$ , the supplier ships at  $i = 1$ . That is, she under-ships. In this case, the supplier sacrifices operational profit to avoid financing cost.

We refer to the supplier's payoff under this solution as  $\Pi_2^C$ , which follows:

$$\Pi_2^C = \begin{cases} \Pi_3 - l\theta_2\beta_2T, & \text{for } T \leq \frac{(1-\beta_2)r-r_0}{l\beta_2}; \\ \Pi_2, & \text{for } T > \frac{(1-\beta_2)r-r_0}{l\beta_2}. \end{cases} \quad (69)$$

2. The insurer cancels only at  $i = 3$ . The optimal contract in this scenario is summarized in Lemma E.4 (cancels at  $i = 3$ ). We refer to the solution in this case *Solution C.3*. Under this solution, the supplier ships at  $i = 1, 2$ . Thus, both the cancelation and the shipping policies are efficient. However, depending on the values of the parameters, the supplier may incur financing cost (due to a high deductible) and/or surrender rent to the insurer (when the premium is greater than the insurer's expected cost). We refer to the supplier's payoff under this solution as  $\Pi_3^C$ , which is detailed in Lemma E.4.

For contracts that induce other cancelation policies (e.g., the insurer only cancels at  $i = 2$ ), as shown in Lemma E.5, they are all (weakly) dominated by Solution C.2 or Solution C.3 as discussed above. Thus, it is sufficient to compare  $\Pi_2^C$  (Solution C.2 in Lemma E.3) and  $\Pi_3^C$  (Solution C.3 in Lemma E.4) when identifying the optimal cancelable contract.

To compare the two solutions, we define the efficiency loss of a solution as the difference between the first-best payoff in this case,  $\Pi_3 = r \sum_{i=1}^2 \theta_i(1 - \beta_i) + \theta_3 r_0 - c$  and the supplier's payoffs,  $\Pi_3^C$  or  $\Pi_2^C$ . Specifically, we denote  $\Delta_3^C = \Pi_3 - \Pi_3^C$  and  $\Delta_2^C = \Pi_3 - \Pi_2^C$ . According to Lemma E.3 and Lemma E.4, we have:

$$\Delta_2^C = \begin{cases} l\theta_2\beta_2T, & \text{for } T \leq \frac{(1-\beta_2)r-r_0}{l\beta_2}; \\ \theta_2[(1-\beta_2)r-r_0], & \text{for } T > \frac{(1-\beta_2)r-r_0}{l\beta_2}. \end{cases} \quad (70)$$

As for  $\Delta_3^C$ , we have that for  $\beta_2 \leq \bar{\beta}$  (corresponding Solution C.3.L in Lemma E.4),

$$\Delta_3^C = \begin{cases} 0, & \text{for } c \geq \theta_1(\beta_2 - \beta_1) \max\left(r - \frac{r-r_0}{\beta_3}, \frac{T}{1-\beta_2}\right); \\ \theta_1(\beta_2 - \beta_1) \left(r - \frac{r-r_0}{\beta_3}\right) - c, & \text{for } c < \theta_1(\beta_2 - \beta_1) \max\left(r - \frac{r-r_0}{\beta_3}, \frac{r - \frac{r-r_0}{\beta_3} + lT}{1+(1-\beta_2)l}\right); \\ \left(\frac{l}{l_h}\right) \left[\frac{\theta_1(\beta_2 - \beta_1)T}{1-\beta_2} - c\right], & \text{for } c \in \left[\frac{\theta_1(\beta_2 - \beta_1) \left(r - \frac{r-r_0}{\beta_3} + lT\right)}{1+(1-\beta_2)l}, \frac{\theta_1(\beta_2 - \beta_1)T}{(1-\beta_2)}\right] \text{ and } l \leq l_h; \\ \frac{\theta_1(\beta_2 - \beta_1)T}{1-\beta_2} - c, & \text{for } c \in \left[\frac{\theta_1(\beta_2 - \beta_1) \left(r - \frac{r-r_0}{\beta_3} + lT\right)}{1+(1-\beta_2)l}, \frac{\theta_1(\beta_2 - \beta_1)T}{(1-\beta_2)}\right] \text{ and } l > l_h; \end{cases} \quad (71)$$

where  $l_h$  is defined in Lemma E.4. Similarly,  $\Delta_3^C$  for  $\beta_2 > \bar{\beta}$  corresponds Solution C.3.H in Lemma E.4.

With this notation, we discuss two cases: when  $\beta_2 \leq \bar{\beta}$  and  $\beta_2 > \bar{\beta}$ .

First, when  $\beta_2 \leq \bar{\beta}$ , based on Lemma E.3, we observe that for any  $T$ ,  $\Delta_2^C$  is independent in  $c$ . By considering Lemma E.4, and in particular, Solution 3.L, we note that for any given  $T$ ,  $\Delta_3^C$  is continuous and decreasing in  $c$  when considering each region independently, and  $\Delta_3^C$  is continuous on  $c$  at the boundaries between different regions. Combining the monotonicity of  $\Delta_2^C$  and  $\Delta_3^C$ , it is clear that for any  $T$ , there exists a function  $\phi_1^C(T) \in [0, \phi]$  in the Proposition such that Solution C.2 is optimal if and only if  $c \leq \phi_1^C(T)$ . In this case, according to Lemma E.3, the supplier ships at  $i = 1, 2$  when  $T \leq (l\beta_2)^{-1}[(1-\beta_2)r-r_0]$ , corresponding to the

under-insured (*UI*) region in the Proposition. When  $T > (l\beta_2)^{-1}[(1 - \beta_2)r - r_0]$ , the supplier only ships at  $i = 1$ , corresponding to the under-ship (*US*) region in the Proposition.

When  $c > \phi_1^C(T)$ , we note that Solution C.3.L is optimal. In addition, by Lemma E.4, we have that  $\Pi_3^C = \Pi_3$  when  $c \geq \phi_{FV}^C(T)$  as defined, and by Lemma E.3,  $\Pi_2^C < \Pi_3$  when  $c = \phi_{FV}^C(T)$ . Thus, by the monotonicity and continuity of  $\Pi_3^C$  as proved above, we can show that  $\phi_{FV}^C(T) \geq \phi_1^C(T)$ . Thus, we have that when  $c \geq \phi_{FV}^C(T)$ , the supplier receives the full value of TCI under Solution C.3, corresponding the *FV* region in the Proposition, and when  $c \in [\phi_1^C(T), \phi_{FV}^C(T))$ , the supplier incurs financing cost or surrenders rent to the insurer, corresponding to the *RI/FC* region in the first table in the Proposition.

Next, we consider the case with  $\beta_2 < \bar{\beta}$ . The difference between this case and the previous one ( $\beta_2 \geq \bar{\beta}$ ) is in Solution C.3. In this case, the corresponding solution is Solution C.3.H. The first observation of Solution C.3.H is that  $\Pi_3^C < \Pi_3$  (due to the rent surrounded to the insurer and possibly financing cost). Combining this with  $\Pi_2^C < \Pi_3$  (Solution C.2), it is clear that the cancelable contract cannot recover the full value of TCI in this region. Next, we note that in Solution C.3.H, for any  $T$ ,  $\Delta_3^C$  first strictly decreases in  $c$  and then strictly increases in  $c$ . On the other hand,  $\Delta_2^C$  is independent of  $c$ . Thus, there exists  $\phi_2^C(T)$  and  $\phi_3^C(T)$  where  $0 \leq \phi_2^C(T) \leq \phi_3^C(T) \leq \phi$  such that  $\Pi_3^C \geq \Pi_2^C$  if and only if  $c \in [\phi_2^C(T), \phi_3^C(T)]$ . This corresponds to the *RI/FC* region in the second table. When  $c < \phi_2^C(T)$  and  $c > \phi_3^C(T)$ ,  $\Pi_2^C > \Pi_3^C$ , and the structure of *UI* and *US* regions is the same as in the first table.  $\square$

**Proof of Proposition 5.** We first consider the case with  $\beta_2 \leq \bar{\beta}$  and compare the optimal cancelable contract (Proposition 4) and the optimal non-cancelable one (Proposition B.1). Let the supplier's payoff under the optimal cancelable contract be  $\Pi^{C,*}$ , which equals  $\max(\Pi_2^C, \Pi_3^C)$  as defined in the proof of Proposition 4, and in Lemmas E.3 and E.4. Similarly, let the supplier's payoff that under the optimal non-cancelable contract be  $\Pi^{N,*}$ , which equals to  $\max(\Pi_0, \Pi_3^{NB}, \Pi_2^{NB}, \Pi_2^{NN})$  as defined in the proof of Proposition B.1, and in Lemma E.1. Similar to the proof in Proposition 4, we define the inefficiency gap as  $\Delta^{C,*} = \Pi_3 - \Pi^{C,*} = \min(\Delta_2^C, \Delta_3^C)$ , and  $\Delta^{N,*} = \max(\Delta_0, \Delta_3^{NB}, \Delta_2^{NB}, \Delta_2^{NN})$ . Under this notation, the supplier prefers the cancelable contract if and only if  $\Delta^{C,*} \leq \Delta^{N,*}$ .

By the proof of Proposition 4, for a given  $T$ , we note that for  $c \geq \phi_{FV}^C(T)$ , the optimal cancelable contract leads to  $\Delta^{C,*} = 0 \leq \Delta^{N,*}$ . For  $c < \phi_{FC}^C(T)$ , we have  $\frac{d\Delta^{C,*}}{dc} \in [-1, 0]$ . As for  $\Delta^{N,*}$ , by considering Proposition B.1 and the proof, for any given  $T$ , we have the following two cases:

1. If  $\phi_3^{NL}(T) \leq \phi_{FV}^C(T)$ , we have that for  $c \in [\phi_3^{NL}(T), \phi_{FV}^C(T)]$ ,  $\frac{d\Delta^{N,*}}{dc} = -1$ , thus  $\Delta^{N,*} > \Delta^{C,*}$  in this region. As for  $c < \phi_3^{NL}(T)$ ,  $\Delta^{N,*}$  (weakly) increases in  $c$ . Thus,  $\Delta^{N,*}$  and  $\Delta^{C,*}$  can cross at most once in this region.
2. If  $\phi_3^{NL}(T) > \phi_{FV}^C(T)$ , by the same argument, for  $c < \phi_{FV}^C(T)$ ,  $\Delta^{N,*}$  (weakly) increases in  $c$ . Thus,  $\Delta^{N,*}$  and  $\Delta^{C,*}$  can cross at most once in this region.

Combining the above two scenarios, we can show that there exists a threshold function  $\phi_L(T)$  such that the supplier prefers the cancelable contract when  $c > \phi_L(T)$  and the non-cancelable one when  $c \leq \phi_L(T)$ , as desired.

In the case with  $\beta_2 > \bar{\beta}$ , using the same notation as in the previous case, we have for  $c \leq \phi_{FV}^{NL}(T)$ ,  $\Delta^{N,*} = 0$ . And we also have  $\Delta^{N,*} \leq \Pi_3 - \Pi_0 = 0$  at  $c = \phi$ . As for the cancelable contract, we have  $\Delta^{C,*} > 0$  for all  $c$ .

Thus, 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  $c > \phi_{H,2}(T)$ , as desired.  $\square$

**Proof of Proposition B.2.** When  $r_0 < (1 - \beta_2)r$ , in order for the supplier to receive the full value of TCI under a partially cancelable contract, the necessary and sufficient conditions are:

1. The insurer exerts effort;
2. The supplier ships at  $i = 1, 2$ ;
3. The supplier does not incur financing cost; and
4. The insurance premium equals to the insurer's expected costs.

In order for the four conditions to hold jointly, the insurer's cancelation policy can only be one of the following two scenarios:

1. The insurer only cancels at  $i = 3$ ;
2. The insurer cancels at  $i = 2, 3$ .

Next, we identify the feasible sets that satisfy the four conditions above by considering these two scenarios.

**Scenario I: The insurer only cancels at  $i = 3$ .** Under this cancelation policy, the four necessary and sufficient conditions to be satisfied jointly is equivalent to that the following inequalities should hold simultaneously.

$$p \geq f; \tag{72}$$

$$p = c + \sum_{i \leq 2} \theta_i \beta_i (r - \delta) + \theta_3 f; \tag{73}$$

$$r_0 \leq r - \bar{\beta}[\delta + L(r - \delta - p)]; \tag{74}$$

$$f + \bar{\beta}\gamma \geq c + \sum_{i \leq 2} \theta_i \beta_i (r - \delta) + \theta_3 f; \tag{75}$$

$$\bar{\beta}(r - \delta) \geq c + \sum_{i \leq 2} \theta_i \beta_i (r - \delta) + \theta_3 f; \tag{76}$$

$$f + \beta_2 \gamma \geq \beta_2 (r - \delta); \tag{77}$$

$$f < \beta_3 (r - \delta); \tag{78}$$

$$r_0 < r - \beta_2 [r - \gamma + L(\gamma + f - p)]; \tag{79}$$

$$r_0 \geq r - \beta_3 [r - \gamma + L(\gamma + f - p)]; \tag{80}$$

$$r_0 \leq r - \beta_3 [\delta + L(r - \delta - p)]; \tag{81}$$

$$r - \delta - p \geq T. \tag{82}$$

Among these conditions, (72) follows from the constraint that the refund is no greater than the premium. (73) makes sure that the premium equals to the insurer's expected cost (claim and refund, whichever is applicable). Following the proof in Lemma B.1, (74) – (76) jointly guarantee that the insurer has the incentive to exert effort under the supplier's anticipated action. (79) – (80) jointly guarantee that without coverage, the supplier ships only at  $i \leq 2$ . This is because if the supplier does not ship at  $i = 2$  without coverage, the

optimization problem degenerates to corresponds to a pure cancelable contract. (81) says that the supplier ships at  $i \leq 3$  if her coverage is not canceled. (77) and (78) confirm that the insurer cancels only at  $i = 3$ . The asymmetry between the two conditions is because that without coverage, the supplier ships at  $i = 2$ , but not  $i = 3$ . Thus, the insurer's total cost under cancelation is  $f + \beta_2\gamma$  at  $i = 2$ , but only  $f$  at  $i = 3$ . Thus, the insurer's total cost under cancelation is  $f + \beta_2\gamma$  at  $i = 2$ , but only  $f$  at  $i = 3$ . (82) makes sure that when the supplier ships under coverage, she does not incur financing cost. Finally, note that  $\gamma$  does not enter the objective function directly as it is only used to discipline the insurer, and the supplier actually never ships when the contract is canceled.

The above set of constraints can be simplified as follows: first, given (76), (78) is redundant. Second, when (82) holds, (81) can be simplified to

$$\delta \leq \frac{r - r_0}{\beta_3}. \quad (83)$$

Third, notice that everything else being equal, increasing  $\gamma$  loosens all the constraints except for (80). Therefore, we can set  $\gamma$  so that (80) is binding, i.e.,

$$\gamma = r - \frac{r - r_0}{\beta_3} + \frac{l}{1+l} \left[ T + c - \tau_3 - (1 - \theta_3)f + \sum_{i=1}^2 \theta_i \beta_i \left( \frac{r - r_0}{\beta_3} - \delta \right) \right]^+, \quad (84)$$

where  $\tau_i = \left(1 - \sum_{j < i} \theta_j \beta_j\right) \left(r - \frac{r - r_0}{\beta_i}\right)$ , which is also defined in Lemma E.1. Note that the above equation also guarantees that (79) is satisfied. Fourth, (84) implies that  $\gamma \geq r - \frac{r - r_0}{\beta_3}$ . Therefore, for the region of  $c$  that we are interested in, i.e.,  $c \leq \phi = \theta_3[r_0 - (1 - \beta_3)r]$ , we have that  $\theta_3\beta_3\gamma \geq c$ . Under this condition, when (77) holds, (75) becomes redundant.

After applying these four simplifications, the set of inequalities (75) – (82) can be simplified to the following set.

$$\gamma = r - \frac{r - r_0}{\beta_3} + \frac{l}{1+l} \left[ T + c - \tau_3 - (1 - \theta_3)f + \sum_{i=1}^2 \theta_i \beta_i \left( \frac{r - r_0}{\beta_3} - \delta \right) \right]^+; \quad (85)$$

$$\delta \leq \frac{r - r_0}{\beta_3}; \quad (86)$$

$$f \geq \beta_2(r - \gamma - \delta); \quad (87)$$

$$f \leq \frac{\left(1 - \sum_{i=1}^2 \theta_i \beta_i\right)(r - \delta) - (T + c)}{\theta_3}; \quad (88)$$

$$f \leq \frac{c + \sum_{i=1}^2 \theta_i \beta_i(r - \delta)}{1 - \theta_3}; \quad (89)$$

$$f \leq \beta_3(r - \delta) - \frac{c}{\theta_3}. \quad (90)$$

Among these constraints, note that (88) – (90) all set an upper bound for  $f$  and have the following interpretation: (88) ensures that the supplier does not incur any financing cost when shipping under coverage ( $i = 1, 2$ ); (89) says that refund cannot be greater than premium; and (90) ensures that it is better for the insurer to exert effort than to not exert effort and never cancel. By comparing these three constraints, we can discuss the conditions under which the set of inequalities has a feasible solution based on the following two scenarios regarding the magnitude of  $\delta$ .

**Scenario I.A.** For  $\delta \leq \min \left( r - \frac{c + (1 - \theta_3)T}{1 - \theta_3 - \sum_{i=1}^2 \theta_i \beta_i}, r - \frac{c}{\theta_3(\beta_3 - \bar{\beta})} \right)$ , (88) is binding, and hence,

$$\gamma = r - \frac{r - r_0}{\beta_3} + \frac{l}{1 + l} \left[ T - \left( r - \frac{r - r_0}{\beta_3} \right) \right]^+. \quad (91)$$

As such, (85) – (90) can be simplified to:

$$\delta \leq r - \frac{c + (1 - \theta_3)T}{1 - \theta_3 - \sum_{i=1}^2 \theta_i \beta_i}; \quad (92)$$

$$\delta \leq r - \frac{c}{\theta_3(\beta_3 - \bar{\beta})}; \quad (93)$$

$$\delta \leq \frac{r - r_0}{\beta_3}; \quad (94)$$

$$\delta \geq \frac{r - r_0}{\beta_3} - \frac{c + \sum_{i=1}^2 \theta_i \beta_i \left( r - \frac{r - r_0}{\beta_3} \right) + \frac{(1 - \theta_3)\beta_2 l}{1 + l} \left[ T - \left( r - \frac{r - r_0}{\beta_3} \right) \right]^+}{\theta_1(\beta_2 - \beta_1)}. \quad (95)$$

Note that (95) ensures that if binding,  $\delta \leq \frac{r - r_0}{\beta_3}$ . Thus, (94) will not be the one that determines the feasibility of the above set of inequalities. By comparing (92) and (93), we have the following two scenarios.

**Scenario I.A.a.** For  $c \geq \frac{\theta_3(\beta_3 - \bar{\beta})}{1 - \bar{\beta}}T$ , (93) is tighter than (92). Therefore, there exists a feasible  $\delta$  if and only if

$$\frac{(\bar{\beta} - \beta_2)c}{\theta_3(\beta_3 - \bar{\beta})} + \beta_2 \left( r - \frac{r - r_0}{\beta_3} + \frac{l}{1 + l} \left[ T - \left( r - \frac{r - r_0}{\beta_3} \right) \right]^+ \right) \geq 0. \quad (96)$$

It is easy to check that this inequality also holds for  $c \leq \phi$ . Thus, (92) – (95) has a feasible solution for all  $c$  such that

$$c \geq \frac{\theta_3(\beta_3 - \bar{\beta})}{1 - \bar{\beta}}T. \quad (97)$$

**Scenario I.A.b.** For  $c < \frac{\theta_3(\beta_3 - \bar{\beta})}{1 - \bar{\beta}}T$ , (92) is tighter than (93), and hence there exists a feasible  $\delta$  for (92) – (95) if and only if:

$$c \geq \frac{\theta_1(\beta_2 - \beta_1)T - (1 - \theta_3 - \sum_{i=1}^2 \theta_i \beta_i)\beta_2 \left( r - \frac{r - r_0}{\beta_3} + \frac{l}{1 + l} \left[ T - \left( r - \frac{r - r_0}{\beta_3} \right) \right]^+ \right)}{1 - \beta_2}, \quad (98)$$

Combining (98) and (97) leads to the condition (15) in the proposition.

**Scenario I.B.** For  $\delta > \min \left( r - \frac{c + (1 - \theta_3)T}{1 - \theta_3 - \sum_{i=1}^2 \theta_i \beta_i}, r - \frac{c}{\theta_3(\beta_3 - \bar{\beta})} \right)$ , either (89) or (90) is binding. With some algebra, we can show that the first-best payoff cannot be achieved outside the region as defined in (15) in the Proposition. The details are omitted for expositional brevity.  $\square$

#### D.4. Proof in Section 7

**Proof of Lemma B.2.** For the first part of the lemma, we note that as the information is unverifiable, the supplier can only update her prior belief and act correspondingly based on the insurer's cancellation decision (the message). In addition, as the insurer and supplier act sequentially, there is no benefit for the supplier to adopt a mixed strategy regarding her shipping decision. Therefore, we have in total four possibilities of how the supplier reacts to the insurer's cancellation action.

1. The supplier ships whether the insurer cancels or not.

2. The supplier does not ship whether the insurer cancels or not.
3. The supplier ships when the insurer cancels, and does not ship when he does not cancel.
4. The supplier ships when the coverage is not canceled, and does not ship when the insurer cancels.

Clearly, for the first and third scenarios, the insurer should never cancel as the supplier does not ship any way. Thus, he does not exert effort either, which contradicts with the assumption in the Lemma that the contract induces the insurer's effort. For the second scenario, as the supplier always ships, the only benefit of the insurer's cancellation is to limit his own cost. However, as the insurance market is competitive, such benefit will be reflected in the premium. Thus, the insurer should not exert effort either. This leaves us only to the last scenario, and hence proves the first part of the lemma.

For the second part, we prove it by contradiction. Assume that the insurer cancels at signal  $i$ , but does not cancel at signal  $i + 1$ . Then by the lemma above, the supplier does not ship at signal  $i$  and ships at signal  $i + 1$ . Anticipating the supplier's shipping policy, this cancellation policy is optimal to the insurer only if:

$$f \leq \beta_i(r - \delta); \quad (99)$$

$$f \geq \beta_{i+1}(r - \delta). \quad (100)$$

However, as  $\beta_i < \beta_{i+1}$ , these two inequalities cannot hold simultaneously, which contradicts with our assumption. This concludes the proof of the second part of the Lemma.

Finally, for the third part of the Lemma, we note that a PBE consists of a sequentially rational strategy profile, which includes the insurer's cancellation strategy and the supplier's shipping strategy in our case, and the supplier's posterior belief. For the specified cancellation strategy and shipping strategy to be in the PBE, we must have the following two conditions hold jointly:

1. The insurer has no incentive to deviate from the specific cancellation strategy. This condition further requires two conditions: 1) the insurer has the incentive to cancel coverage at  $i \geq j$ , which holds if and only if  $f \leq \beta_j(r - \delta)$ . 2) The insurer has no incentive to cancel at  $i \leq j - 1$ , which holds if and only if  $f \geq \beta_{j-1}(r - \delta)$ . Combining these conditions leads to  $\mathbb{B}_P \in [\beta_{j-1}, \beta_j]$ , which is the first condition in the lemma.
2. The supplier ships if and only if  $i < j$ . This condition consists of two parts:
  - (a) the supplier ships at all  $i < j$ , which leads to

$$r - \frac{\sum_{i \leq j} \theta_i \beta_i}{\sum_{i \leq j} \theta_i} [\delta - L(r - \delta - p)] \geq r_0, \quad (101)$$

where  $\frac{\sum_{i \leq j} \theta_i \beta_i}{\sum_{i \leq j} \theta_i}$  is the supplier's posterior belief of the buyer's default risk after observing that the coverage is not canceled. The above condition can be re-written as  $\frac{\sum_{i \leq j} \theta_i \beta_i}{\sum_{i \leq j} \theta_i} \leq \mathbb{B}(p, \delta)$ , corresponding to the second condition in the Lemma;

- (b) the supplier does not ship at all  $i \geq j$ , which leads to

$$r - \frac{\sum_{i > j} \theta_i \beta_i}{\sum_{i > j} \theta_i} [r + L(f - p)] \leq r_0, \quad (102)$$

where  $\frac{\sum_{i > j} \theta_i \beta_i}{\sum_{i > j} \theta_i}$  is the supplier's posterior belief of the buyer's default risk upon receiving the cancellation message. The above condition can be re-written as  $\frac{\sum_{i > j} \theta_i \beta_i}{\sum_{i > j} \theta_i} \geq \mathbb{B}_C(p, f)$ , corresponding to the third condition in the Lemma.  $\square$

**Proof of Proposition 6.** In order to identify the optimal contract, we need to first identify conditions under which the insurer has the incentive to exert effort in anticipation of the outcome of the signaling subgame, in which the insure decides whether to cancel and the supplier decides when to ship. The analysis is similar to that in Lemma B.1 and the proof. By that, we can identify that under contract  $(p, \delta, f)$ , the insurer exerts effort if and only if the following three conditions hold jointly:

$$\mathbb{B} \leq \bar{\beta}; \quad (103)$$

$$\bar{\beta}(r - \delta) \geq c + (r - \delta) \sum_i \theta_i \beta_i \mathbb{1}_{\beta_i \leq \mathbb{B}_P} + f \sum \theta_i \mathbb{1}_{\beta_i > \mathbb{B}_P} \quad (104)$$

$$f \geq c + (r - \delta) \sum_i \theta_i \beta_i \mathbb{1}_{\beta_i \leq \mathbb{B}_P} + f \sum \theta_i \mathbb{1}_{\beta_i > \mathbb{B}_P}. \quad (105)$$

The three conditions are analogous to (12) – (14) in Lemma B.1. The proof is also similar to that in Lemma B.1, and the only difference is the right hand side of (104) – (105), which equals to the insurer's expected cost under the cancelation policy depicted in Lemma B.2.

With the above conditions, we can determine the optimal cancelable contract by identifying the optimal contract that induces different cancelation policies. According to Lemma B.2, it is sufficient to consider the following two scenarios:

1. The insurer cancels at  $i = 2, 3$  (Scenario 1, Solution U.2).
2. The insurer cancels at  $i = 3$  (Scenario 2, Solution U.3).

In the following, we first solve these two scenarios separately, and then compare the performance of the two when necessary.

**Step 1: optimal contracts that induce the insurer to cancel at  $i = 2, 3$  (Solution U.2).** For this case, the corresponding optimization problem is as follows:

$$\max_{p, \delta, f \leq p} -p + \theta_1 \{r - \beta_1[\delta + L(r - \delta - p)]\} + (\theta_2 + \theta_3)(r_0 + f); \quad (106)$$

$$\text{s.t. } r_0 \leq r - \bar{\beta}[\delta + L(r - \delta - p)]; \quad (107)$$

$$\bar{\beta}(r - \delta) \geq c + \theta_1 \beta_1(r - \delta) + (\theta_2 + \theta_3)f; \quad (108)$$

$$f \geq c + \theta_1 \beta_1(r - \delta) + (\theta_2 + \theta_3)f; \quad (109)$$

$$f \geq \beta_1(r - \delta); \quad (110)$$

$$f \leq \beta_2(r - \delta); \quad (111)$$

$$r_0 \geq r - \frac{\theta_2 \beta_2 + \theta_3 \beta_3}{\theta_2 + \theta_3} [r + L(f - p)]; \quad (112)$$

$$r_0 \leq r - \beta_1[\delta + L(r - \delta - p)]. \quad (113)$$

In the optimization problem, (106) is the supplier's payoff. (107) – (109) follow directly from (103) – (105) with the insurer's specific cancelation policy, and (110) – (113) follow directly from (16) – (18) with the insurer's specific cancelation policy and the supplier's shipping policy. Note that compared to their counterparts under verifiable information, i.e., Eq. (66) – (67), Eq. (112) – (113) are less restrictive. Thus, it is straightforward that the optimal solution under the unverifiable information case should lead to a (weakly) higher value in the objective than that under the verifiable information case.

Next, we note that for Eq. (112) to hold, as  $f \leq p$ , the parameter must satisfy:

$$T \geq l^{-1} \left[ \frac{(\theta_2 + \theta_3)(r - r_0)}{\theta_2\beta_2 + \theta_3\beta_3} - r \right]. \quad (114)$$

Otherwise, the above optimization problem has no feasible solution.

Under (114), we verify that the contract  $p = f = \frac{c}{\theta_1} + \beta_1 r$ , and  $\delta = 0$  is a feasible solution to Eq. (106) – (113): Based on the proof in Proposition 3, it is clear that Eq. (107) – (111) are all satisfied under the above contract. (113) is automatically satisfied under (107). In addition, we note that under  $p = f = \frac{c}{\theta_1} + \beta_1 r$ , and  $\delta = 0$ , the supplier's payoff is  $\Pi_2^U = \Pi_2$ , the highest payoff the supplier can achieve under such policies.

Next, we apply the above optimal contract to the following different scenarios depending on the supplier's outside option.

1. When  $r_0 \geq (1 - \beta_2)r$ , (114) is satisfied. Thus, the above contract allows the supplier to fully recover the value of TCI. Thus, we do not need to consider the other contracting option. This corresponds to the first statement in Proposition 6.
2. When  $r_0 < (1 - \beta_2)r$ ,
  - (a) When  $T \geq -\frac{C_2}{l \sum_{i \geq 2} \theta_i \beta_i}$ , (114) is satisfied. Thus, under this scenario, the insurer over-cancels, i.e., he cancels at  $i = 2$  even though it is efficient to ship at  $i = 2$ .
  - (b) When  $T < -\frac{C_2}{l \sum_{i \geq 2} \theta_i \beta_i}$ , this solution is infeasible.

**Step 2: Optimal contracts that induce the insurer to cancel at  $i = 3$  (Solution U.3).** For this case, the optimization problem is as follows.

$$\max_{p, \delta \in [0, r], f \leq p} -p + \sum_{i=1}^2 \theta_i \{r - \beta_i [\delta + L(r - p - \delta)]\} + \theta_3(r_0 + f); \quad (115)$$

$$\text{s.t. } r_0 \leq r - \bar{\beta}[\delta + L(r - \delta - p)]; \quad (116)$$

$$\bar{\beta}(r - \delta) \geq c + \sum_{i=1}^2 \theta_i \beta_i (r - \delta) + \theta_3 f; \quad (117)$$

$$f \geq c + \sum_{i=1}^2 \theta_i \beta_i (r - \delta) + \theta_3 f; \quad (118)$$

$$f \geq \beta_2(r - \delta); \quad (119)$$

$$f < \beta_3(r - \delta); \quad (120)$$

$$r_0 \geq r - \beta_3[r + L(f - p)]; \quad (121)$$

$$r_0 \leq r - \left( \frac{\theta_1 \beta_1 + \theta_2 \beta_2}{\theta_1 + \theta_2} \right) [\delta + L(r - \delta - p)]. \quad (122)$$

Solving this optimization problem leads to the following results regarding the optimal contracts and the supplier's payoff  $\Pi_3^U$ . We refer the readers to Lemma E.6 for the details in the detailed solution. In summary, the shipping and cancelation decision in this Solution is efficient when  $r_0 > (1 - \beta_2)r$ . However, depending on the value of parameters, the supplier may incur financing cost and/or surrender rent to the insurer.

**Step 3: Compare Solutions U.2 and U.3.** Next, we compare Solution U.2 ( $\Pi_2^U$ ) and Solution U.3 ( $\Pi_3^U$ ) according to the following scenarios.

1. For  $r_0 \geq (1 - \beta_2)r$ , the full value of TCI is  $\Pi_2$ . Based on Solution U.2.,  $\Pi_2^U = \Pi_2$ , i.e., the supplier receives the full value of TCI. This corresponds to the first statement in the Proposition.
2. For  $r_0 < (1 - \beta_2)r$ , the full value of TCI is  $\Pi_3$ . We have two further cases.
  - (a) If  $\beta_2 \leq \bar{\beta}$ , for  $c \geq \phi_{FV}^U(T)$  as defined in the Proposition,  $\Pi_3^U = \Pi_3$ , i.e., the supplier receives the full value of TCI. For  $c < \phi_{FV}^U(T)$ , at a given  $T$ , by Lemma E.6, the inefficiency gap  $\Delta_3^U := \Pi_3 - \Pi_3^U$  decreases in  $c$ , which  $\Delta_2^U := \Pi_3 - \Pi_2^U$  is independent of  $c$ . Thus, there exists a threshold function  $\phi_1^U(T)$  such that  $\Delta_3^U \leq \Delta_2^U$  if and only if  $c \geq \phi_1^U(T)$ . This corresponds to Statement 2.i) in the Proposition.
  - (b) If  $\beta_2 \leq \bar{\beta}$ , we note  $\Delta_3^U > 0$ . In addition, according to Lemma E.6,  $\Delta_3^U$  first decreases and then increases in  $c$ , and  $\Delta_2^U$  is still independent of  $c$ . Therefore, there exists two threshold functions  $\phi_2^U(T) \leq \phi_3^U(T)$  such that  $\Delta_3^U \leq \Delta_2^U$  if and only if  $c \in [\phi_2^U(T) \leq \phi_3^U(T)]$ . This corresponds to Statement 2.ii) in the Proposition.  $\square$

**Proof of Proposition 7.** The proof is analogous to that of Proposition 5. We consider the following two scenarios.

1. When  $\beta_2 \leq \bar{\beta}$ , we further consider two cases.
  - (a) for  $r_0 \leq (1 - \beta_2)r$ , we have the supplier's payoff under the optimal cancelable contract  $\Pi^{U,*} = \Pi_2^U = \Pi_2$ , the first-best benchmark. Thus, the supplier always prefers the cancelable contract.
  - (b) for  $r_0 > (1 - \beta_2)r$ , we have that when  $c > \phi_{FV}^U(T)$ ,  $\Pi^{U,*} = \Pi_2^U = \Pi_3$ , the first-best benchmark. Further,  $\Pi^{U,*}$  (weakly) decreases in  $c$ , while the supplier's payoff under the non-cancelable contract,  $\Pi_0$ , is independent of  $c$ . Thus,  $\Pi^{U,*} > \Pi_0$  for all  $c$ .
 Combining the above two cases, we prove that cancelable contract is preferred when  $\beta_2 \leq \bar{\beta}$  (Statement 1 in the Corollary).
2. When  $\beta_2 > \bar{\beta}$ , as  $\Pi^{U,*} = \max(\Pi_2^U, \Pi_3^U)$ . According to the proof in Proposition 6,  $\Pi^{U,*} < \Pi_3$ . On the other hand, the payoff under the non-cancelable contract,  $\Pi_0 = \Pi_3$  at  $c = \phi$ . Thus, at  $c = \phi$ ,  $\Pi^{U,*} < \Pi_0$ . Further, we note that  $\Pi_0$  is independent of  $c$ , while  $\Pi^{U,*}$  (weakly) decreases in  $c$ . Thus, there exists  $\phi_H^U(T)$  such that  $\Pi^{U,*} \geq \Pi_0$  if and only if  $c \leq \phi_H^U(T)$ . This corresponds to the second statement.  $\square$

## Appendix E: Technical Lemmas

**Lemma E.1** A non-cancelable contract under which the supplier ships if and only if at  $\beta_1, \dots, \beta_{i-1}$ , for  $i \geq 2$ , exists if and only if  $\beta_i \geq \bar{\beta}$ . and  $c \leq r \sum_{j \geq i} \theta_j \beta_j$ .

Under these two conditions, the optimal non-cancelable contract terms  $(\delta, p)$  and the supplier's corresponding payoff are:

1. for  $c \leq C_i^U + \frac{l \sum_{j \geq i} \theta_j \beta_j}{1 + (1 - \beta)l} [T - (\tau_i - C_i^U)]^+$ , the contract terms are:

$$\delta = \frac{r - r_0}{\beta_i} - \frac{l(T + c - \tau_i)^+}{1 + l(1 - \sum_{j < i} \theta_j \beta_j)}, \quad p = c + \sum_{j \leq i-1} \theta_j \beta_j (r - \delta). \quad (123)$$

The supplier's corresponding payoff is:

$$\Pi_i^N = \Pi_i - \frac{l \sum_{j < i} \theta_j \beta_j}{1 + l(1 - \sum_{j < i} \theta_j \beta_j)} (T + c - \tau_i)^+ := \Pi_i^{NB}. \quad (124)$$

Under this contract, the insurer's IR constraint is binding.

2. for  $c > C_i^U + \frac{l \sum_{j \geq i} \theta_j \beta_j}{1 + (1 - \bar{\beta})l} [T - (\tau_i - C_i^U)]^+$ , the contract terms are:

$$\delta = r - \frac{c}{\sum_{j \geq i} \theta_j \beta_j}, \quad p = \frac{1}{l} \left( \frac{r - r_0}{\beta_i} - r \right) + \left( 1 + \frac{1}{l} \right) \frac{c}{\sum_{j \geq i} \theta_j \beta_j} - T. \quad (125)$$

The supplier corresponding payoff is:

$$\Pi_i^N = \Pi_i - \left[ \frac{(1 - \bar{\beta})lc + (1 + \sum_{j < i} \theta_j \beta_j l)(c - C_i^U)}{l \sum_{j \geq i} \theta_j \beta_j} - T \right] := \Pi_i^{NN}. \quad (126)$$

Under this contract, the insurer's IR constraint is not binding.

By comparing  $\Pi_i^N$  ( $\Pi_i^{NB}$  and  $\Pi_i^{NN}$ ) with the optimal payoff without effort  $\Pi_0$  (Lemma 2), we have:

1.  $\Pi_i^{NB} \geq \Pi_0$  if and only if

$$c \leq \min \left( C_i - \frac{l \sum_{j < i} \theta_j \beta_j}{1 + l} [T - (\tau_i - C_i)], C_i^U + \frac{l \sum_{j \geq i} \theta_j \beta_j}{1 + (1 - \bar{\beta})l} [T - (\tau_i - C_i^U)]^+ \right). \quad (127)$$

2.  $\Pi_i^{NN} \geq \Pi_0$  if and only if

$$c \in \left( C_i^U + \frac{l \sum_{j \geq i} \theta_j \beta_j}{1 + (1 - \bar{\beta})l} [T - (\tau_i - C_i^U)]^+, C_i^U + \frac{l \sum_{j \geq i} \theta_j \beta_j}{1 + l} [T - (\tau_i - C_i)] \right]. \quad (128)$$

**Lemma E.2** For any  $j, k, m \in \{1, 2, 3\}$ , among all cancelable contracts that induces the insurer to cancel at signal  $i \in [j, m]$  and the supplier ships if and only if the signal  $i \leq \max(j - 1, k)$ , the optimal contract is the solution to the following optimization problem:

$$\max_{\substack{p, \delta \in [0, r] \\ f \leq p}} r_0 - p + \sum_{i < j} \theta_i [(r - r_0) - \beta_i (\delta + L(r - p - \delta))] + \sum_{i=j}^k \theta_i [(r - r_0) - \beta_i (r + L(f - p))] + \sum_{i=j}^m \theta_i f; \quad (129)$$

$$\mathbb{B} \geq \bar{\beta}; \quad (130)$$

$$\bar{\beta}(r - \delta) \geq c + \sum_{i < j} \theta_i \beta_i (r - \delta) + \sum_{i \in [j, m]} \theta_i f; \quad (131)$$

$$f \geq c + \sum_{i < j} \theta_i \beta_i (r - \delta) + \sum_{i \in [j, m]} \theta_i f; \quad (132)$$

$$\mathbb{B} \in (\beta_m, \beta_{m+1}]; \quad (133)$$

$$\mathbb{B}_P \in [\beta_{j-1}, \beta_j]; \quad (134)$$

$$\mathbb{B}_C \in (\beta_k, \beta_{k+1}]. \quad (135)$$

**Lemma E.3 (Solution C.2)** For  $r_0 < (1 - \beta_2)r$ , a cancelable contract in which the insurer cancels coverage at  $i = 2, 3$  is feasible if and only if:

$$c \leq \theta_1 [\min(\bar{\beta}, \beta_2) - \beta_1]r. \quad (136)$$

Within this region, the optimal contract is :

$$\delta = 0; \quad p = f = \frac{c}{\theta_1} + \beta_1 r. \quad (137)$$

Under this contract, the insurer's payoff is zero.

1. for  $T \leq \frac{(1 - \beta_2)r - r_0}{l\beta_2}$ , the supplier ships at  $i = 1, 2$ , and her payoff  $\Pi_2^C = \Pi_3 - l\theta_2\beta_2 T$ ;

2. for  $T > \frac{(1-\beta_2)r-r_0}{l\beta_2}$ , the supplier ships at  $i=1$ , and her payoff  $\Pi_2^C = \Pi_2$ .

**Lemma E.4 (Solution C.3)** Let  $l_h = \frac{\theta_1(\beta_2-\beta_1)}{\sum_{i=1}^2 \theta_i \beta_i (1-\beta_2)}$ . For  $r_0 < (1-\beta_2)r$ , the optimal cancelable contract under which the insurer cancels only at  $i=3$ , and the supplier's corresponding payoff  $\Pi_3^C$ , is summarized as follows.

For  $\beta_2 \leq \bar{\beta}$  (**Solution C.3.L**),  $p = f = \frac{c + \sum_{i=1}^2 (r-\delta)}{\sum_{i=1}^2 \theta_i}$ ,

1. for  $c \geq \theta_1(\beta_2 - \beta_1) \max\left(r - \frac{r-r_0}{\beta_3}, \frac{T}{1-\beta_2}\right)$ ,  $\delta = \left(r - \frac{c}{\theta_1(\beta_2-\beta_1)}\right)^+$ , and  $\Pi_3^C = \Pi_3$ ;
2. for  $c < \theta_1(\beta_2 - \beta_1) \max\left(r - \frac{r-r_0}{\beta_3}, \frac{r - \frac{r-r_0}{\beta_3} + lT}{1+(1-\beta_2)l}\right)$ ,  $\delta = \frac{r-r_0}{\beta_3}$ , and  $\Pi_3^C = \Pi_3 - \left[\theta_1(\beta_2 - \beta_1) \left(r - \frac{r-r_0}{\beta_3}\right) - c\right]$ ;
3. for  $c \in \left[\frac{\theta_1(\beta_2-\beta_1)(r - \frac{r-r_0}{\beta_3} + lT)}{1+(1-\beta_2)l}, \frac{\theta_1(\beta_2-\beta_1)T}{(1-\beta_2)}\right)$ ;
  - (a) if  $l \leq l_h$ ,  $\delta = r - \frac{c}{\theta_1(\beta_2-\beta_1)}$ ;  $\Pi_3^C = \Pi_3 - \left(\frac{l}{l_h}\right) \left[\frac{\theta_1(\beta_2-\beta_1)T}{1-\beta_2} - c\right]$ ;
  - (b) if  $l > l_h$ ,  $\delta = r - \frac{T}{1-\beta_2}$ , and  $\Pi_3^C = \Pi_3 - \left[\frac{\theta_1(\beta_2-\beta_1)T}{1-\beta_2} - c\right]$ ;

For  $\beta_2 > \bar{\beta}$  (**Solution C.3.H**),  $p = f = \beta_2(r - \delta)$  and

1. for  $c \geq \theta_3(\beta_3 - \beta_2) \max\left(r - \frac{r-r_0}{\beta_3}, \frac{T}{1-\beta_2}\right)$ ,  $\delta = r - \frac{c}{\theta_3(\beta_3-\beta_2)}$ , and  $\Pi_3^C = \Pi_3 - \frac{(\beta_2-\bar{\beta})c}{\theta_3(\beta_3-\beta_2)}$ ;
2. for  $c < \theta_3(\beta_3 - \beta_2) \left(r - \frac{r-r_0}{\beta_3}\right)$  and  $T \leq (1 - \beta_2) \left(r - \frac{r-r_0}{\beta_3}\right)$ ,  $\delta = \frac{r-r_0}{\beta_3}$ , and  $\Pi_3^C = \Pi_3 - \left[\theta_1(\beta_2 - \beta_1) \left(r - \frac{r-r_0}{\beta_3}\right) - c\right]$ ;
3. for  $c < \frac{\theta_3(\beta_3-\beta_2)T}{(1-\beta_2)}$  and  $T > (1 - \beta_2) \left(r - \frac{r-r_0}{\beta_3}\right)$ ,
  - (a) if  $l \leq l_h$  and  $c < \frac{\theta_3(\beta_3-\beta_2) \left[r - \frac{r-r_0}{\beta_3} + lT\right]}{1+(1-\beta_2)l}$ ,  $\delta = r - \frac{r - \frac{r-r_0}{\beta_3} + lT}{1+(1-\beta_2)l}$ , and
 
$$\Pi_3^C = \Pi_3 - \left[\frac{\theta_1(\beta_2 - \beta_1) \left(r - \frac{r-r_0}{\beta_3} + lT\right)}{1 + (1 - \beta_2)l} - c\right] - \sum_{i=1}^2 \theta_i \beta_i l \left[\frac{T - (1 - \beta_2) \left(r - \frac{r-r_0}{\beta_3}\right)}{1 + (1 - \beta_2)l}\right]; \quad (138)$$
  - (b) if  $l \leq l_h$  and  $c \in \left[\frac{\theta_3(\beta_3-\beta_2) \left[r - \frac{r-r_0}{\beta_3} + lT\right]}{1+(1-\beta_2)l}, \frac{\theta_3(\beta_3-\beta_2)T}{1-\beta_2}\right)$ ,  $\delta = r - \frac{c}{\theta_3(\beta_3-\beta_2)}$ ,  $\Pi_3^C = \Pi_3 - \frac{(\beta_2-\bar{\beta})c}{\theta_3(\beta_3-\beta_2)} - \sum_{i=1}^2 \theta_i \beta_i l \left[T - \frac{(1-\beta_2)c}{\theta_3(\beta_3-\beta_2)}\right]$ ;
  - (c) if  $l > l_h$ ,  $\delta = r - \frac{T}{1-\beta_2}$ , and  $\Pi_3^C = \Pi_3 - \left(\frac{\theta_1(\beta_2-\beta_1)T}{1-\beta_2} - c\right)$ .

**Lemma E.5** For  $r_0 < (1-\beta_2)r$ , the supplier's payoff under any cancelable contract that induces the insurer to exert effort and cancel coverage at at least one group of signals is (weakly) dominated by either  $\Pi_2^C$  (Solution C.2, Lemma E.3) or  $\Pi_3^C$  (Solution C.3, Lemma E.4).

**Lemma E.6 (Solution U.3)** The solution to Eq. (115) – (122) in the proof of Proposition 6, and the supplier's corresponding payoff  $\Pi_3^U$ , is summarized as follows.

When  $\beta_2 \leq \bar{\beta}$  (**Solution U.3.L**),  $p = f = \frac{c + \sum_{i=1}^2 (r-\delta)}{\sum_{i=1}^2 \theta_i}$ , and

1. for  $c \geq \frac{\theta_1(\beta_2-\beta_1)T}{1-\beta_2}$ ,  $\delta = \left(r - \frac{c}{\theta_1(\beta_2-\beta_1)}\right)^+$ , and  $\Pi_3^U = \Pi_3$ ;
2. for  $c \in \left[\frac{\theta_1(\beta_2-\beta_1)(r - \frac{r-r_0}{\beta_3} + lT)}{1+(1-\beta_2)l}, \frac{\theta_1(\beta_2-\beta_1)T}{(1-\beta_2)}\right)$ ,
  - (a) for  $l \leq l_h$ ,  $\delta = r - \frac{c}{\theta_1(\beta_2-\beta_1)}$ , and  $\Pi_3^U = \Pi_3 - l \sum_{i=1}^2 \theta_i \beta_i \left[T - \frac{(1-\beta_2)c}{\theta_1(\beta_2-\beta_1)}\right]$ ;
  - (b) for  $l > l_h$ ,  $\delta = r - \frac{T}{1-\beta_2}$ , and  $\Pi_3^U = \Pi_3 - \left[\frac{\theta_1(\beta_2-\beta_1)T}{1-\beta_2} - c\right]$ ;

3. for  $c < \frac{\theta_1(\beta_2 - \beta_1)\left(r - \frac{r-r_0}{\beta} + lT\right)}{1+(1-\beta_2)l}$ ,  $\delta = \frac{r-r_0}{\beta} - \frac{l\left[T-(1-\beta_2)\left(r - \frac{r-r_0}{\beta}\right)\right]}{1+l(1-\beta_2)}$ , and

$$\Pi_3^U = \Pi_3 - \left[ \frac{\theta_1(\beta_2 - \beta_1)\left(r - \frac{r-r_0}{\beta} + lT\right)}{1+(1-\beta_2)l} - c \right] - l \sum_{i=1}^2 \theta_i \beta_i \left[ \frac{T-(1-\beta_2)\left(r - \frac{r-r_0}{\beta}\right)}{1+(1-\beta_2)l} \right]. \quad (139)$$

When  $\beta_2 > \bar{\beta}$  (**Solution U.3.H**),  $p = f = \beta_2(r - \delta)$  and

1. for  $c \geq \frac{\theta_3(\beta_3 - \beta_2)T}{1-\beta_2}$ ,  $\delta = r - \frac{c}{\theta_3(\beta_3 - \beta_2)}$ , and  $\Pi_3^U = \Pi_3 - \frac{(\beta_2 - \bar{\beta})c}{\theta_3(\beta_3 - \beta_2)}$ ;

2. for  $c < \frac{\theta_3(\beta_3 - \beta_2)T}{1-\beta_2}$ ,

(a) for  $l \leq l_h$  and  $c \in \left[ \frac{\theta_3(\beta_3 - \beta_2)\left[r - \frac{r-r_0}{\beta} + lT\right]}{1+(1-\beta_2)l}, \frac{\theta_3(\beta_3 - \beta_2)T}{1-\beta_2} \right)$ ,  $\delta = r - \frac{c}{\theta_3(\beta_3 - \beta_2)}$ , and

$$\Pi_3^U = \Pi_3 - \frac{(\beta_2 - \bar{\beta})c}{\theta_3(\beta_3 - \beta_2)} - l \sum_{i=1}^2 \theta_i \beta_i \left[ T - \frac{(1-\beta_2)c}{\theta_3(\beta_3 - \beta_2)} \right]; \quad (140)$$

(b) for  $l \leq l_h$  and  $c < \frac{\theta_3(\beta_3 - \beta_2)\left[r - \frac{r-r_0}{\beta} + lT\right]}{1+(1-\beta_2)l}$ ,  $\delta = r - \frac{r - \frac{r-r_0}{\beta} + lT}{1+(1-\beta_2)l}$ , and

$$\Pi_3^U = \Pi_3 - \left[ \frac{\theta_1(\beta_2 - \beta_1)\left(r - \frac{r-r_0}{\beta} + lT\right)}{1+(1-\beta_2)l} - c \right] - l \sum_{i=1}^2 \theta_i \beta_i \left[ \frac{T-(1-\beta_2)\left(r - \frac{r-r_0}{\beta}\right)}{1+(1-\beta_2)l} \right]; \quad (141)$$

(c) for  $l \geq l_h$ ,  $\delta = r - \frac{T}{1-\beta_2}$ , and  $\Pi_3^U = \Pi_3 - \left[ \frac{\theta_1(\beta_2 - \beta_1)T}{1-\beta_2} - c \right]$ .

## Appendix F: Proofs of Technical Lemmas

**Proof of Lemma E.1.** Following the analysis in Section 5, for the supplier to only ship at  $j = 1, \dots, i-1$ , the contract must induce the insurer's monitoring effort. Therefore, the optimization problem that determines this optimal non-cancelable contract must have (5) as the objective, and (2) – (4), as well as  $\mathbb{B}(p, \delta) \in (\beta_{i-1}, \beta_i]$  as constraints. For ease of reference, we re-write the optimization problem as follows.

$$\max_{p, \delta \in [0, r]} r_0 - p + \sum_{j \leq i-1} \theta_j \{ (1 - \beta_j)r + \beta_j[r - \delta - L(r - \delta - p)] - r_0 \}; \quad (142)$$

$$\mathbb{B} \geq \bar{\beta}; \quad (143)$$

$$\delta \leq r - \frac{c}{\sum_{j \geq i} \theta_j \beta_j}; \quad (144)$$

$$p \geq c + (r - \delta) \sum_{j \leq i-1} \theta_j \beta_j; \quad (145)$$

$$\mathbb{B} \in (\beta_{i-1}, \beta_i]. \quad (146)$$

By comparing (143) and (146), we note that the math program has no feasible solution when  $\beta_i < \bar{\beta}$ . In addition, we note that for  $\delta \geq 0$  to satisfy (144), we need  $c \leq r \sum_{j \geq i} \theta_j \beta_j$ .

Under the condition  $\beta_i \geq \bar{\beta}$ , note that, according to (1),  $\mathbb{B}$  decreases in both  $\delta$  and  $p$ . Thus, (143) and  $\mathbb{B} > \beta_{i-1}$ , i.e., the left half in (146), are both relaxed as  $\delta$  or  $p$  decreases. Further, note that as  $L(x)$  is weakly decreasing in  $x$ , the objective decreases in both  $\delta$  and  $p$ . Therefore, (143) and  $\mathbb{B} > \beta_{i-1}$  will not be the binding constraint for the optimization problem. In other words, the optimal solution is determined by (142), (144) – (145) and  $\mathbb{B} \leq \beta_i$ , the last of which can be re-written as:

$$\delta + L(r - \delta - p) \geq \frac{r - r_0}{\beta_i}. \quad (147)$$

Jointly considering (144), (145), and (147), we note that (144) does not involve  $p$ . Therefore, at the optimal solution  $(p, \delta)$ , at least one of (145) and (147) must be binding, otherwise,  $(p - \epsilon, \delta)$  increases the objective while not violating any constraints.

Next, we show that any  $(p, \delta)$  under which (147) is not binding must be (weakly) dominated by another solution. To see that, let  $(p, \delta)$  be jointly determined by (144) and (145), that is,

$$\delta_a = r - \frac{c}{\sum_{j \geq i} \theta_j \beta_j}; \quad (148)$$

$$p_a = c + (r - \delta) \sum_{j \leq i-1} \theta_j \beta_j. \quad (149)$$

If (147) is not binding under the above contract, we can confirm that the contract  $\delta_{a1} = \delta_a - \epsilon$  and  $p_{a1} = p_a + \epsilon \sum_{j \leq i-1} \theta_j \beta_j$  for sufficiently small  $\epsilon > 0$  is also a feasible solution that it satisfies (144), (145), and (147). In addition, substituting the above contract into the objective function, which then becomes:

$$\pi_{a1} := r_0 - p_{a1} + \sum_{j \leq i-1} \theta_j \{ (1 - \beta_j)r + \beta_j[r - \delta_{a1} - L(r - \delta_{a1} - p_{a1})] - r_0 \} \quad (150)$$

$$= r_0 - p_a + \sum_{j \leq i-1} \theta_j \left\{ (1 - \beta_j)r + \beta_j[r - \delta_a - L(r - \delta_a - p_a + \epsilon \sum_{j \geq i} \theta_j \beta_j)] - r_0 \right\}. \quad (151)$$

Next, consider two scenarios:

1. if  $L(r - \delta_a - p_a) > 0$ , then  $\pi_{a1}$  is greater than the payoff under contract  $(p_a, \delta_a)$  as  $L(x)$  decreases in  $x$ . Therefore,  $(p_{a1}, \delta_{a1})$  strictly dominates  $(p_a, \delta_a)$ .
2. if  $L(r - \delta_a - p_a) = 0$ , then let  $\epsilon = \frac{r-r_0}{\beta_i} - \delta_a$ . By construction, (147) is binding at  $(p_{a1}, \delta_{a1})$ , which also satisfy (144) and (145), and  $\pi_{a1}$  equals to that under  $(p_a, \delta_a)$ .

Combining the above two scenarios, we can see that any solution  $(p, \delta)$  that is not binding at (147) is (weakly) dominated. Therefore, it is sufficient for us to consider contract  $(p, \delta)$  such that (147) is binding. Under this condition, we analyze the optimal solution depending on whether the other binding constraint is (144) or (145). Consider the following two scenarios.

1. If both (144) and (147) are binding, the contract deductible  $\delta$  is determined by:

$$\delta = r - \frac{c}{\sum_{j \geq i} \theta_j \beta_j} =: \delta_i^{NN}. \quad (152)$$

and the premium  $p$  is implicitly determined by:

$$\delta = \frac{r - r_0}{\beta_i} - L(r - \delta - p); \quad (153)$$

As  $L(\cdot) \geq 0$ , we have  $\delta \leq \frac{r-r_0}{\beta_i}$ , thus  $c$  must satisfy:

$$c \geq \sum_{j \geq i} \theta_j \beta_j \left( r - \frac{r - r_0}{\beta_i} \right) = C_i^U. \quad (154)$$

Under this condition, a feasible premium  $p$  exists if and only if it satisfies the following two equations.

$$L\left(\frac{c}{\sum_{j \geq i} \theta_j \beta_j} - p\right) = \frac{c - C_i^U}{\sum_{j \geq i} \theta_j \beta_j}. \quad (155)$$

$$p \geq \frac{\bar{\beta}}{\sum_{j \geq i} \theta_j \beta_j} c. \quad (156)$$

Further consider two scenarios,

(a) if  $c = C_i^U$ , then a feasible  $p$  exists if and only if  $T - \frac{(1-\bar{\beta})c}{\sum_{j \geq i} \theta_j \beta_j} \leq 0$ , or equivalently,

$$c \geq \frac{\sum_{j \geq i} \theta_j \beta_j}{1 - \bar{\beta}} T. \quad (157)$$

(b) if  $c > C_i^U$ , then according to (155),  $p$  follows  $l(T - r + \delta_{iC,i}^{NC} + p) = \frac{c - C_i^U}{\sum_{j \geq i} \theta_j \beta_j}$ , or equivalently,

$$p = \left(1 + \frac{1}{l}\right) \frac{c}{\sum_{j \geq i} \theta_j \beta_j} - \frac{1}{l} \left(r - \frac{r - r_0}{\beta_i}\right) - T =: p_i^{NN}, \quad (158)$$

which satisfies (156) if and only if:

$$\left(1 + \frac{1}{l}\right) \frac{c}{\sum_{j \geq i} \theta_j \beta_j} - \frac{1}{l} \left(r - \frac{r - r_0}{\beta_i}\right) - T \geq \frac{\bar{\beta}c}{\sum_{j \geq i} \theta_j \beta_j}. \quad (159)$$

or equivalently,

$$c \geq \frac{C_i^U + lT \sum_{j \geq i} \theta_j \beta_j}{1 + l(1 - \bar{\beta})} =: \Phi_i^U(T). \quad (160)$$

which covers the region as defined in (157).

Combining the above two scenarios, we have that when  $c \geq \max(C_i^U, \Phi_i^U(T))$ , the optimal contract terms is  $(p_i^{NN}, \delta_i^{NN})$  as defined above. Correspondingly, the supplier's payoff is:

$$\Pi_i^N = r_0 - p_i^{NN} + \sum_{j < i} \theta_j \{ (1 - \beta_j)r + \beta_j[r - \delta_i^{NN} - L(r - \delta_i^{NN} - p_i^{NN})] - r_0 \} \quad (161)$$

$$= \Pi_i - \left[ \frac{(1 - \bar{\beta})lc + (1 + l \sum_{j < i} \theta_j \beta_j)(c - C_i^U)}{l \sum_{j \geq i} \theta_j \beta_j} - T \right] =: \Pi_i^{NN}. \quad (162)$$

2. If both (145) and (147) are binding, according to (145),  $(p, \delta)$  satisfy:

$$p = c + \sum_{j \leq i-1} \theta_j \beta_j (r - \delta). \quad (163)$$

Substituting this into (147) leads to:

$$\delta + L \left( \left[ 1 - \sum_{j \leq i-1} \theta_j \beta_j \right] (r - \delta) - c \right) = \frac{r - r_0}{\beta_i}, \quad (164)$$

To determine whether  $\delta$  as determined by the above equation can also satisfy (144), we further consider two scenarios.

(a) If  $\delta$  results in  $L \left( \left[ 1 - \sum_{j \leq i-1} \theta_j \beta_j \right] (r - \delta) - c \right) = 0$ , it must follow  $\delta = \frac{r - r_0}{\beta_i}$ . Such  $\delta$  satisfies both (144) and  $L \left( \left[ 1 - \sum_{j \leq i-1} \theta_j \beta_j \right] (r - \delta) - c \right) = 0$  if and only if both of the following conditions are satisfied:

$$\frac{r - r_0}{\beta_i} \leq r - \frac{c}{\sum_{j \geq i} \theta_j \beta_j}; \quad (165)$$

$$\left( 1 - \sum_{j \leq i-1} \theta_j \beta_j \right) \left( \frac{r - r_0}{\beta_i} \right) - c \geq T. \quad (166)$$

or equivalently,

$$c \leq \min(C_i^U, \tau_i - T). \quad (167)$$

- (b) If  $\delta$  results in  $L\left(\left[1 - \sum_{j \leq i-1} \theta_j \beta_j\right](r - \delta) - c\right) > 0$ , using the functional form of  $L()$ ,  $\delta$  follows  $\delta + l\left(T - \left[1 - \sum_{j \leq i-1} \theta_j \beta_j\right](r - \delta) + c\right) = \frac{r - r_0}{\beta_i}$ , or equivalently,

$$\delta = \frac{r - r_0}{\beta_i} - \frac{l(T + c - \tau_i)}{1 + l(1 - \sum_{j \leq i-1} \theta_j \beta_j)}. \quad (168)$$

Such a  $\delta$  satisfies (144) and  $L\left(\left[1 - \sum_{j \leq i-1} \theta_j \beta_j\right](r - \delta) - c\right) > 0$  if and only if:

$$\frac{r - r_0}{\beta_i} - \frac{l(T + c - \tau_i)}{1 + l(1 - \sum_{j \leq i-1} \theta_j \beta_j)} \leq r - \frac{c}{\sum_{j \geq i} \theta_j \beta_j}, \quad \text{and} \quad (169)$$

$$\left[1 - \sum_{j \leq i-1} \theta_j \beta_j\right] \left(r - \frac{r - r_0}{\beta_i} + \frac{l(T + c^E - \tau_i)}{1 + l(1 - \sum_{j \leq i-1} \theta_j \beta_j)}\right) - c^E < T. \quad (170)$$

Or equivalently,

$$c \in (\tau_i - T, \Phi_i^U(T)], \quad (171)$$

which is non-empty if and only if

$$T > \tau_i - C_i^U. \quad (172)$$

Combining the above two scenarios, we have that when  $c \leq \max(C_i^U, \Phi_i^U(T))$ , the binding constraints are (145) and (147), and the optimal deductible is:

$$\delta = \frac{r - r_0}{\beta_i} - \frac{l(T + c - \tau_i)^+}{1 + l(1 - \sum_{j \leq i-1} \theta_j \beta_j)} =: \delta_i^{NB} \quad (173)$$

and the premium  $p$  follows directly from (145), i.e.,

$$p = c + \sum_{j \leq i-1} \theta_j \beta_j (r - \delta_i^{NB}) =: p_i^{NB}. \quad (174)$$

The supplier's corresponding payoff is:

$$\Pi_i^N = r_0 + \sum_{j < i} \theta_j \{ (1 - \beta_j)r - \beta_j L(r - \delta_{iR,i}^{NC} - p_{iR,i}^{NC}) - r_0 \} - c \quad (175)$$

$$= \Pi_i - \frac{\sum_{j < i} \theta_j \beta_j l(T + c - \tau_i)^+}{1 + l(1 - \sum_{j < i} \theta_j \beta_j)} =: \Pi_i^{NB}. \quad (176)$$

Finally, note that  $C_i^U < \Phi_i^U(T)$  if and only if

$$T > (1 - \bar{\beta}) \left( r - \frac{r - r_0}{\beta_i} \right) = \tau_i - C_i^U. \quad (177)$$

Under this condition, note that

$$\Phi_i^U(T) = C_i^U + \frac{l \sum_{j \geq i} \theta_j \beta_j}{1 + (1 - \bar{\beta})l} [T - (\tau_i - C_i^U)]. \quad (178)$$

Therefore,

$$\max(C_i^U, \Phi_i^U(T)) = C_i^U + \frac{l \sum_{j \geq i} \theta_j \beta_j}{1 + (1 - \bar{\beta})l} [T - (\tau_i - C_i^U)]^+, \quad (179)$$

corresponding the boundary that separates the two cases in the lemma.

Next, we compare  $\Pi_i^N$  ( $\Pi_i^{NN}$  and  $\Pi_i^{NB}$ ) with the no effort solution  $\Pi_0$  to prove the final part of the lemma.

In parallel to the above two scenarios, we have:

1. By comparing  $\Pi_i^{NB}$  and  $\Pi_0$  (the first scenario in the lemma), we have:

$$\Pi_i^{NB} - \Pi_0 = \Pi_i - \Pi_0 - \frac{\sum_{j < i} \theta_j \beta_j l (T + c - \tau_i)^+}{1 + l(1 - \sum_{j < i} \theta_j \beta_j)}. \quad (180)$$

As  $\Pi_i - \Pi_0 = C_i - c$ ,  $\Pi_i^{NB} - \Pi_0 \geq 0$  if and only if

$$c \leq C_i - \frac{l \sum_{j < i} \theta_j \beta_j}{1 + l} [T - (\tau_i - C_i)]. \quad (181)$$

In addition, note that according to the above result,  $\Pi_i^{NB}$  is only feasible when  $c \leq C_i^U + \frac{l \sum_{j \geq i} \theta_j \beta_j}{1 + (1 - \beta)l} [T - (\tau_i - C_i^U)]^+$ . Combining these two conditions, we have that  $\Pi_i^{NB}$  dominates  $\Pi_0$  if and only if (127) (in the Lemma) holds.

2. By comparing  $\Pi_i^{NN}$  (the second scenario in the lemma) and  $\Pi_0$ , we have:

$$\Pi_i^{NN} - \Pi_0 = C_i - c - \left[ \frac{(1 - \bar{\beta})lc + (1 + l \sum_{j < i} \theta_j \beta_j)(c - C_i^U)}{l \sum_{j \geq i} \theta_j \beta_j} - T \right]. \quad (182)$$

Therefore,  $\Pi_i^{NN} \geq \Pi_0$  if and only if:

$$c \leq C_i^U + \frac{l \sum_{j \geq i} \theta_j \beta_j}{1 + l} [T - (\tau_i - C_i)]. \quad (183)$$

Combining with the condition that defines the feasibility of optimality of  $\Pi_i^{NN}$ , i.e.,  $c > C_i^U + \frac{l \sum_{j > i} \theta_j \beta_j}{1 + (1 - \beta)l} [T - (\tau_i - C_i^U)]^+$ , we obtain that  $\Pi_i^{NN}$  dominates  $\Pi_0$  if and only if (128) holds.  $\square$

**Proof of Lemma E.2.** As the insurer cancels at  $i \in [j, m]$ , we have  $\mathbb{B} \in (\beta_m, \beta_{m+1})$ , i.e., Eq. (133), and  $\mathbb{B}_P \in [\beta_{j-1}, \beta_j)$ , i.e., Eq. (134). Similarly, as the supplier ships when signal  $i \leq \max(j-1, k)$ , and  $\mathbb{B}_P \in [\beta_{j-1}, \beta_j)$ , we have  $\mathbb{B}_C \in (\beta_k, \beta_{k+1}]$ , i.e., Eq. (135).

With the above mapping, we note that for any expression  $x$ , we have  $\sum_{i < j} x = \sum_i x \mathbb{1}_{\beta_i < \mathbb{B}_P}$ ,  $\sum_{i \in [j, k]} x = \sum_i x \mathbb{1}_{\beta_i \in [\mathbb{B}_P, \mathbb{B}_C]}$  and  $\sum_{i \in [j, m]} x = \sum_i x \mathbb{1}_{\beta_i \in [\mathbb{B}_P, \mathbb{B}]}$ . With the above substitution, the supplier's payoff (129) follows from (8), and (130)–(132) follow directly from (12) – (14) in Lemma B.1.  $\square$

**Proof of Lemma E.3.** We first show that Eq. (136) is necessary for such a cancelable contract to be feasible. Based on Lemma E.2 and using its notation, a cancelable contract with  $j = 2$  and  $k = 3$  is feasible if and only if the set of following inequalities has a solution.

$$\mathbb{B} \geq \bar{\beta}; \quad (184)$$

$$\bar{\beta}(r - \delta) \geq c + \theta_1 \beta_1(r - \delta) + (\theta_2 + \theta_3)f; \quad (185)$$

$$f \geq c + \theta_1 \beta_1(r - \delta) + (\theta_2 + \theta_3)f; \quad (186)$$

$$p \geq c + \theta_1 \beta_1(r - \delta) + (\theta_2 + \theta_3)f; \quad (187)$$

$$f < \beta_2(r - \delta); \quad (188)$$

$$f \geq \beta_1(r - \delta); \quad (189)$$

$$\mathbb{B} > \beta_3. \quad (190)$$

As  $p \geq f$ , given (186), (187) is redundant. When (190) holds, (184) becomes redundant. Further, when (186) holds, (189) is redundant. Therefore, the above set of inequalities can be simplified as:

$$f \leq \frac{(\theta_2\beta_2 + \theta_3\beta_3)(r - \delta) - c}{\theta_2 + \theta_3}; \quad (191)$$

$$f \geq \frac{c}{\theta_1} + \beta_1(r - \delta); \quad (192)$$

$$f < \beta(r - \delta); \quad (193)$$

$$\mathbb{B} > \beta_3. \quad (194)$$

Note that (191) and (192) can hold jointly if and only if

$$\frac{(\theta_2\beta_2 + \theta_3\beta_3)(r - \delta) - c}{\theta_2 + \theta_3} \geq \frac{c}{\theta_1} + \beta_1(r - \delta), \quad (195)$$

or equivalently,

$$c \leq \theta_1(\bar{\beta} - \beta_1)(r - \delta). \quad (196)$$

Similarly, (192) and (193) can hold jointly if and only if:

$$c \leq \theta_1(\beta_2 - \beta_1)(r - \delta). \quad (197)$$

Combining (196) and (197), and setting  $\delta = 0$ , which makes both constraints the least stringent, leads to (136) as desired.

Second, we combine the sufficient side with identifying the optimal solution. Note that under the above cancelation policy, the supplier can have two possible shipping policies: first, she ships at  $i = 1$ ; second, she ships at  $i = 1, 2$  (and hence the shipment is uninsured at  $i = 2$ ). In the following, we first establish the best possible payoff the supplier can achieve under each shipping policy, and then show that the contract in the lemma, i.e., (137), allows the supplier to achieve this payoff as long as (136) is satisfied.

1. If the supplier ships at  $i = 1$ , the best possible payoff she can receive is  $\Pi_2$ . Next, note that under the contract (137), the supplier has no incentive to ship at  $i = 2$  when  $T > \frac{(1-\beta_2)r-r_0}{l\beta_2}$ . And in this region, under the contract (137), her payoff is indeed  $\Pi_2$ . Therefore, (137) is optimal.
2. If the supplier ships at  $i = 1, 2$ , as the shipment is uninsured at  $i = 2$ , the best possible payoff she can receive is  $\Pi_3 - \theta_2\beta_2lT$ . Symmetrical to the previous case, the supplier has the incentive to ship at  $i = 2$  when  $T \leq \frac{(1-\beta_2)r-r_0}{l\beta_2}$ . And in this region, under the contract (137), her payoff is indeed  $\Pi_3 - \theta_2\beta_2lT$ . Therefore, (137) is optimal.

Finally, note that the contract (137) has  $\delta = 0$ , thus, it satisfies (184) – (190) under (136). Thus, this contract always induces the specific cancelation and shipping decisions as specified in the lemma as long as (136) is satisfied.  $\square$

**Proof of Lemma E.4.** Based on Lemma E.2 and using its notation, when the insurer only cancels at  $i = 3$ , and the supplier ships at  $i = 1, 2$ , we must have  $j = 3$  (if not, i.e.,  $j < 3$ , then the insurer does not have the incentive to cancel at  $i = 3$ .) and  $k < 3$  (because if  $k = 3$ , then the supplier ships under all signals, and hence the insurer has no incentive to exert effort). By imposing the above  $j$ ,  $k$  and  $m$ , we re-write the optimization problem in Lemma E.2 as follows:

$$\max_{p, \delta \in [0, r], f \leq p} -p + \sum_{i \leq 2} \theta_i \{r - \beta_i [\delta + L(r - f - \delta)]\} + \theta_3(r_0 + f); \quad (198)$$

$$r_0 \leq r - \bar{\beta} [\delta + L(r - \delta - p)]; \quad (199)$$

$$\bar{\beta}(r - \delta) \geq c + \sum_{i \leq 2} \theta_i \beta_i (r - \delta) + \theta_3 f; \quad (200)$$

$$f \geq c + \sum_{i \leq 2} \theta_i \beta_i (r - \delta) + \theta_3 f; \quad (201)$$

$$f < \beta_3(r - \delta); \quad (202)$$

$$f \geq \beta_2(r - \delta); \quad (203)$$

$$r_0 \leq r - \beta_3 [\delta + L(r - \delta - p)]; \quad (204)$$

$$r_0 \geq r - \beta_3 [r + L(f - p)]. \quad (205)$$

We simplify this math program as follows. First, as  $\bar{\beta} < \beta_3$ , given (204), (199) is redundant. Second, note that (200) can be simplified as  $\theta_3 \beta_3 (r - \delta) \geq c + \theta_3 f$ . Under this condition, (202) becomes redundant. Third, as  $L(f - p) \geq 0$  and  $(1 - \beta_3)r < r_0$ , (205) is redundant. Fourth, we note that  $p$  only appears in (198), (204), and in the constraint  $f \leq p$ . As a smaller  $p$  improves the objective function and loosens (204), under the optimal solution, the constraint  $f \leq p$  must be binding, i.e.  $p = f$ . Consolidating all the above steps, we can simplify (198) – (205) as follows.

$$\max_{\delta \in [0, r], f} \sum_{i \leq 2} \theta_i [r - \beta_i (\delta + L(r - f - \delta)) - f] + \theta_3 r_0; \quad (206)$$

$$\text{s.t. } f \leq \beta_3(r - \delta) - \frac{c}{\theta_3}; \quad (207)$$

$$f \geq \frac{c + \sum_{i \leq 2} \theta_i \beta_i (r - \delta)}{\theta_1 + \theta_2}; \quad (208)$$

$$f \geq \beta_2(r - \delta); \quad (209)$$

$$r_0 \leq r - \beta_3 [\delta + L(r - \delta - f)]. \quad (210)$$

We observe that for any given  $\delta$ , decreasing  $f$  improves the objective function. In addition, note that as  $f$  decreases, both (207) and (210) are relaxed. Therefore, at the optimal  $f$ , at least one of (208) and (209) is binding. By comparing the two conditions, we can see that the binding one depends on the magnitude of  $\delta$ . Specifically, by comparing the right hand side of (208) and (209), we note that

$$\frac{c + \sum_{i \leq 2} \theta_i \beta_i (r - \delta)}{\theta_1 + \theta_2} \geq \beta_2(r - \delta) \quad (211)$$

is equivalent to

$$\delta \geq r - \frac{c}{\theta_1(\beta_2 - \beta_1)}. \quad (212)$$

When this condition is satisfied, (208) is the binding constraint, i.e., the insurer does not extract rent. However, the supplier may incur financing cost. Otherwise, (209) is the binding constraint, and the insurer extracts information rent. In the following, we characterize the optimal contract depending on which of the two constraints are binding.

**Scenario I** ( $\delta \geq r - \frac{c}{\theta_1(\beta_2 - \beta_1)}$ ): (208) is the binding constraint, and it can be re-written

$$f = \frac{c + \sum_{i=1}^2 \theta_i \beta_i (r - \delta)}{\sum_{i=1}^2 \theta_i}, \quad (213)$$

and (206) – (210) can be re-written as follows:

$$\max_{\delta \in [0, r]} \Pi_3 - \sum_{i=1}^2 \theta_i \beta_i L \left( \left[ 1 - \frac{\sum_{i=1}^2 \theta_i \beta_i}{\sum_{i=1}^2 \theta_i} \right] (r - \delta) - \frac{c}{\sum_{i=1}^2 \theta_i} \right) \quad (214)$$

$$\text{s.t. } \delta \leq r - \frac{c}{\theta_3(\beta_3 - \bar{\beta})} \quad (215)$$

$$\delta \geq r - \frac{c}{\theta_1(\beta_2 - \beta_1)} \quad (216)$$

$$\delta + L \left( \left[ 1 - \frac{\sum_{i=1}^2 \theta_i \beta_i}{\sum_{i=1}^2 \theta_i} \right] (r - \delta) - \frac{c}{\sum_{i=1}^2 \theta_i} \right) \leq \frac{r - r_0}{\beta_3} \quad (217)$$

where  $\Pi_3$  is the supplier's payoff under the first-best benchmark, and the second term in the objective function captures the potential financing cost the supplier needs to incur. By comparing (215) and (216), we note that the two constraints can jointly hold if and only if

$$\theta_3(\beta_3 - \bar{\beta}) \geq \theta_1(\beta_2 - \beta_1), \quad (218)$$

or equivalently,

$$\beta_2 \leq \bar{\beta}. \quad (219)$$

In other words, if  $\beta_2 \leq \bar{\beta}$ , there exists no cancelable contract under which the insurer does not extract rent with the specified cancellation and shipping policies. In the original optimization problem, the reason lies in the fact that when (201) is binding, (200) and (203) cannot hold jointly if  $\beta_2 > \bar{\beta}$ .

Therefore, in the following analysis of **Scenario I**, we should work under the condition that  $\beta_2 \leq \bar{\beta}$ . In this case, we note that the objective function decreases in  $\delta$ . Therefore, the optimal solution corresponds to the smallest  $\delta$  that satisfies (215) – (217). Further note that both (215) and (217) are loosened as  $\delta$  decreases, hence, the optimal solution should satisfy:

$$\delta = \left( r - \frac{c}{\theta_1(\beta_2 - \beta_1)} \right)^+. \quad (220)$$

We can verify that under this deductible and  $\beta_2 \leq \bar{\beta}$ , (215) always holds. To check whether (217) holds under this contract, we further consider two scenarios, depending on whether  $\delta = 0$ , i.e.,  $r - \frac{c}{\theta_1(\beta_2 - \beta_1)} \leq 0$ .

**Scenario I.A:** For  $c \geq \theta_1(\beta_2 - \beta_1)r$ ,  $\delta = 0$ . We can also verify that (217) holds under all  $T$  that satisfies Assumption 2. Thus, the corresponding optimal contract is:

$$\delta = 0; \quad p = f = \frac{c + \sum_{i=1}^2 \theta_i \beta_i r}{\sum_{i=1}^2 \theta_i}, \quad (221)$$

and the supplier's payoff is  $\Pi_u$ , the first-best benchmark. In other words, the supplier receives the full value of TCI.

**Scenario I.B:** For  $c < \theta_1(\beta_2 - \beta_1)r$ , the possible optimal solution, if feasible, is:

$$\delta = r - \frac{c}{\theta_1(\beta_2 - \beta_1)}; \quad p = f = \frac{\beta_2 c}{\theta_1(\beta_2 - \beta_1)}. \quad (222)$$

This solution is feasible if and only if it satisfies (217), or equivalently,

$$r - r_0 \geq \beta_3 \left[ r - \frac{c}{\theta_1(\beta_2 - \beta_1)} + L \left( \frac{(1 - \beta_2)c}{\theta_1(\beta_2 - \beta_1)} \right) \right]. \quad (223)$$

Note that if this inequality does not hold, then the optimization problem (214) – (217) is infeasible. In other words, there exists no solution in **Scenario I** under which (208) is binding. Thus, depending on whether the supplier can avoid financing cost, i.e.,  $T \leq \frac{(1 - \beta_2)c}{\theta_1(\beta_2 - \beta_1)}$ , we further consider two cases.

**Scenario I.B.a:** for  $T \leq \frac{(1 - \beta_2)c}{\theta_1(\beta_2 - \beta_1)}$ , or equivalently,

$$c \geq \frac{\theta_1(\beta_2 - \beta_1)}{(1 - \beta_2)} T, \quad (224)$$

the supplier can avoid financing cost. Under this condition, (217) holds if and only if:

$$c \geq \theta_1(\beta_2 - \beta_1) \left( r - \frac{r - r_0}{\beta_3} \right). \quad (225)$$

Therefore, we have the following two cases.

1. The contract in (222) achieves first-best  $\Pi_u$  when

$$c \geq \theta_1(\beta_2 - \beta_1) \max \left( r - \frac{r - r_0}{\beta_3}, \frac{T}{1 - \beta_2} \right). \quad (226)$$

2. No contract under **Scenario I** is infeasible when

$$c \in \left( \frac{\theta_1(\beta_2 - \beta_1)}{1 - \beta_2} T, \theta_1(\beta_2 - \beta_1) \left( r - \frac{r - r_0}{\beta_3} \right) \right). \quad (227)$$

**Scenario I.B.b:** for  $T \geq \frac{(1 - \beta_2)c}{\theta_1(\beta_2 - \beta_1)}$ , or equivalently,

$$c \leq \frac{\theta_1(\beta_2 - \beta_1)}{(1 - \beta_2)} T, \quad (228)$$

(223) can be re-written as:

$$c \geq \frac{\theta_1(\beta_2 - \beta_1) \left( r - \frac{r - r_0}{\beta_3} + lT \right)}{1 + (1 - \beta_2)l}. \quad (229)$$

Therefore, we have two cases:

1. Contract (222) is feasible when

$$c \in \left[ \frac{\theta_1(\beta_2 - \beta_1) \left( r - \frac{r - r_0}{\beta_3} + lT \right)}{1 + (1 - \beta_2)l}, \frac{\theta_1(\beta_2 - \beta_1)}{(1 - \beta_2)} T \right]. \quad (230)$$

and the supplier's payoff is  $\Pi_3 - \sum_{i=1}^2 \theta_i \beta_i l \left[ T - \frac{(1 - \beta_2)c}{\theta_1(\beta_2 - \beta_1)} \right]$ .

2. No contract under **Scenario I** is feasible when

$$c \leq \min \left( \frac{\theta_1(\beta_2 - \beta_1)}{(1 - \beta_2)} T, \frac{\theta_1(\beta_2 - \beta_1) \left( r - \frac{r - r_0}{\beta_3} + lT \right)}{1 + (1 - \beta_2)l} \right). \quad (231)$$

Consolidating Scenario I.A, Scenario I.B.a (two sub-cases) and Scenario I.B.b (two sub-cases), the optimal contract in Scenario I (for  $\beta_2 \leq \bar{\beta}$ ) can be summarized as follows.

1. The supplier receives the full value of TCI ( $\Pi_3^C = \Pi_3^E$ ) under contract (221) or (222) when

$$c \geq \theta_1(\beta_2 - \beta_1) \max \left( r - \frac{r - r_0}{\beta_3}, \frac{T}{1 - \beta_2} \right). \quad (232)$$

2. The contract (222) is feasible, but the supplier incurs financing cost when:

$$c \in \left[ \frac{\theta_1(\beta_2 - \beta_1) \left( r - \frac{r - r_0}{\beta_3} + lT \right)}{1 + (1 - \beta_2)l}, \frac{\theta_1(\beta_2 - \beta_1)T}{(1 - \beta_2)} \right]. \quad (233)$$

and the supplier's payoff is:

$$\Pi_3^C = \Pi_3 - \sum_{i=1}^2 \theta_i \beta_i l \left[ T - \frac{(1 - \beta_2)c}{\theta_1(\beta_2 - \beta_1)} \right], \quad (234)$$

3. The contract is infeasible when:

$$c < \theta_1(\beta_2 - \beta_1) \max \left( r - \frac{r - r_0}{\beta_3}, \frac{r - \frac{r - r_0}{\beta_3} + lT}{1 + (1 - \beta_2)l} \right). \quad (235)$$

**Scenario II** ( $\delta \leq r - \frac{c}{\theta_1(\beta_2 - \beta_1)}$ ): (209) is binding. Thus, we have:

$$p = f = \beta_2(r - \delta). \quad (236)$$

Under this contract, the insurer will not cancel coverage at  $i = 2$ . To achieve this, the insurer may extract rent. Substituting the above expression of  $p$  and  $f$  into (206) – (210) leads to:

$$\max_{\delta \in [0, r]} \Pi_3 - [\theta_1(\beta_2 - \beta_1)(r - \delta) - c] - \sum_{i=1}^2 \theta_i \beta_i l [T - (1 - \beta_2)(r - \delta)]^+ \quad (237)$$

$$\text{s.t. } \delta \leq r - \frac{c}{\theta_1(\beta_2 - \beta_1)} \quad (238)$$

$$\delta \leq r - \frac{c}{\theta_1(\beta_2 - \beta_1)} \quad (239)$$

$$\delta \leq \frac{r - r_0}{\beta_3} - \frac{l \left[ T - (1 - \beta_2) \left( r - \frac{r - r_0}{\beta_3} \right) \right]^+}{1 + l(1 - \beta_2)} \quad (240)$$

As shown, the three components of the objective function are: the first-best benchmark  $\Pi_3$ , the information rent surrendered to the insurer, and the expected financing cost. Note that the information rent,  $\theta_1(\beta_2 - \beta_1)(r - \delta) - c$ , decreases in  $\delta$ , while the financing cost is constant in  $\delta$  for  $\delta \leq r - \frac{T}{1 - \beta_2}$ , and increasing in  $\delta$  for  $\delta > r - \frac{T}{1 - \beta_2}$ . Combining these two forces, as  $\delta$  increases from zero, the financing cost initially remains at zero, and hence the objective function increases until  $\delta = r - \frac{T}{1 - \beta_2}$ .<sup>8</sup> For a greater  $\delta$ , the supplier incurs financing cost, and

$$\frac{d\Pi_3^C}{d\delta} = \theta_1(\beta_2 - \beta_1) - l \sum_{i=1}^2 \theta_i \beta_i (1 - \beta_2), \quad (241)$$

which is positive if and only if

$$l < l_h := \frac{\theta_1(\beta_2 - \beta_1)}{\sum_{i=1}^2 \theta_i \beta_i (1 - \beta_2)}. \quad (242)$$

Therefore, the optimal  $\delta$  follows two cases depending whether  $l$  is greater than  $l_h$ .

<sup>8</sup> We can verify that  $\delta = 0$  is a feasible solution to the range of  $c$  that we are interested, i.e.,  $c \leq \phi = \theta_3[r_0 - (1 - \beta_3)r]$  for  $\beta_2 > \bar{\beta}$ , and  $c \leq \theta_1(\beta_2 - \beta_1)r$  for  $\beta_2 \leq \bar{\beta}$ . The second set of conditions comes from the fact that when  $\beta_2 \leq \bar{\beta}$ , the optimal solution in Scenario I.A above can achieve first-best, hence it is unnecessary to consider other solutions.

1. For  $l \leq l_h$ , as  $\delta$  increases, the corresponding increase in financing cost is not as great as the decrease in information rent. Therefore, the optimal contract sets the deductible as high as possible, i.e. at the level that at least one of (238) – (240) is binding. Equivalently,

$$\delta = \min \left( r - \frac{c}{\theta_3(\beta_3 - \beta_2)}, r - \frac{c}{\theta_1(\beta_2 - \beta_1)}, \frac{r - r_0}{\beta_3} - \frac{l \left[ T - (1 - \beta_2) \left( r - \frac{r - r_0}{\beta_3} \right) \right]^+}{1 + l(1 - \beta_2)} \right). \quad (243)$$

2. For  $l > l_h$ , for  $\delta > r - \frac{T}{1 - \beta_2}$ , as  $\delta$  increases, the corresponding increase in financing cost dominates the decrease in information rent. Therefore, the optimal deductible should be:

$$\delta = \min \left( r - \frac{T}{1 - \beta_2}, r - \frac{c}{\theta_3(\beta_3 - \beta_2)}, r - \frac{c}{\theta_1(\beta_2 - \beta_1)}, \frac{r - r_0}{\beta_3} - \frac{l \left[ T - (1 - \beta_2) \left( r - \frac{r - r_0}{\beta_3} \right) \right]^+}{1 + l(1 - \beta_2)} \right). \quad (244)$$

Combining the above two cases in **Scenario II** with the three cases in **Scenario I** that we summarize above, we can fully characterize the optimal contract and the corresponding payoff in the format in Lemma E.4.

First,  $\beta_2 \leq \bar{\beta}$  (Solution C.3.L in Lemma E.4): under this condition, given (239), (238) will not be the binding constraint. Depending on the range of  $c$ ,  $T$ , and  $l$ , we further consider the following cases.

1. When  $c \geq \theta_1(\beta_2 - \beta_1) \max \left( r - \frac{r - r_0}{\beta_3}, \frac{T}{1 - \beta_2} \right)$ , according to Scenario I, the supplier can receive the full value of TCI. This corresponds to the first statement in Solution C.3.L.
2. When  $c < \theta_1(\beta_2 - \beta_1) \max \left( r - \frac{r - r_0}{\beta_3}, \frac{r - r_0}{1 + (1 - \beta_2)l} + lT \right)$ , Scenario I is infeasible. Therefore, we only need to consider the optimal solution in Scenario II. By considering (243) and (244), we have that  $\delta = \frac{r - r_0}{\beta_3}$ , and her payoff is:

$$\Pi_3^C = \Pi_3 - \left[ \theta_1(\beta_2 - \beta_1) \left( r - \frac{r - r_0}{\beta_3} \right) - c \right]. \quad (245)$$

This corresponds to the second statement in Solution C.3.

3. When  $c \in \left[ \frac{\theta_1(\beta_2 - \beta_1) \left( r - \frac{r - r_0}{\beta_3} + lT \right)}{1 + (1 - \beta_2)l}, \frac{\theta_1(\beta_2 - \beta_1)}{(1 - \beta_2)} T \right)$ , Scenario I is feasible. Next, consider the following two cases.

- (a) when  $l > l_h$ , the solution in Scenario II follows (244). By comparing the four scenarios, we can see that the binding one is  $\delta = r - \frac{T}{1 - \beta_2}$ . In this case, the supplier can avoid financing cost, and her payoff:

$$\Pi_3^C = \Pi_3 - \left[ \frac{\theta_1(\beta_2 - \beta_1)T}{1 - \beta_2} - c \right]. \quad (246)$$

Comparing this with the supplier's payoff under the optimal contract in Scenario I (234), we have:

$$\Pi_3 - \left( \frac{\theta_1(\beta_2 - \beta_1)T}{1 - \beta_2} - c \right) - \left[ \Pi_3 - l \sum_{i=1}^2 \theta_i \beta_i \left( T - \frac{(1 - \beta_2)c}{\theta_1(\beta_2 - \beta_1)} \right) \right] \quad (247)$$

$$= (l - l_h) \sum_{i=1}^2 \theta_i \beta_i \left( T - \frac{(1 - \beta_2)c}{\theta_1(\beta_2 - \beta_1)} \right) \geq 0. \quad (248)$$

Thus, the solution in Scenario II, i.e.,  $\delta = r - \frac{T}{1 - \beta_2}$ , is optimal. This corresponds to Solution III.L.3(b) in the lemma.

(b) when  $l \leq l_h$ , the optimal contract under Scenario II, i.e., (243), can be simplified into:

$$\delta = \min \left( r - \frac{c}{\theta_1(\beta_2 - \beta_1)}, r - \frac{r - \frac{r-r_0}{\beta_3} + lT}{1 + (1 - \beta_2)l} \right). \quad (249)$$

Consider the following two cases.

- i. When  $c \in \left[ \frac{\theta_1(\beta_2 - \beta_1) \left[ r - \frac{r-r_0}{\beta_3} + lT \right]}{1 + (1 - \beta_2)l}, \frac{\theta_1(\beta_2 - \beta_1)T}{1 - \beta_2} \right)$ , we can show that the optimal contract under Scenario II, i.e.,  $\delta = r - \frac{c}{\theta_1(\beta_2 - \beta_1)}$ , is the same as in Scenario I. Therefore, the supplier's payoff is the same as in (234). This corresponds to Solution III.L.3(a) in the lemma.
- ii. When  $c < \frac{\theta_1(\beta_2 - \beta_1) \left[ r - \frac{r-r_0}{\beta_3} + lT \right]}{1 + (1 - \beta_2)l}$ , the optimal solution under Scenario II is  $\delta = r - \frac{r - \frac{r-r_0}{\beta_3} + lT}{1 + (1 - \beta_2)l}$ , and the corresponding payoff, following (237), is:

$$\Pi_3^C = \Pi_3 + c - \frac{\theta_1(\beta_2 - \beta_1) \left( r - \frac{r-r_0}{\beta_3} + lT \right)}{1 + (1 - \beta_2)l} - \sum_{i=1}^2 \theta_i \beta_i l \left[ \frac{T - (1 - \beta_2) \left( r - \frac{r-r_0}{\beta_3} \right)}{1 + (1 - \beta_2)l} \right]. \quad (250)$$

With some algebra, we can show that this payoff is always lower than the supplier's payoff under Scenario I, i.e., (234).

Combining these two cases, we can show that for  $l \leq l_h$ , the optimal contract is  $\delta = r - \frac{c}{\theta_1(\beta_2 - \beta_1)}$ , and the supplier's payoff follows (234).

Second,  $\beta_2 > \bar{\beta}$  (Solution III.H in Lemma E.4): in this case, Scenario I is infeasible. Therefore, we only need to consider the solution in Scenario II, as governed by (243) and (244). Further, (238) is tighter than (239). Depending on the range of  $c$ ,  $T$ , and  $l$ , we further consider the following cases.

1. When  $c \geq \theta_3(\beta_3 - \beta_2) \max \left( r - \frac{r-r_0}{\beta_3}, \frac{T}{1 - \beta_2} \right)$ , regardless of  $l$ , we have:  $\delta = r - \frac{c}{\theta_3(\beta_3 - \beta_2)}$ , and the supplier's payoff, following (237), is:

$$\Pi_3^C = \Pi_3 - \frac{(\beta_2 - \bar{\beta})c}{\theta_3(\beta_3 - \beta_2)}. \quad (251)$$

This corresponds to Solution III.H.1.

2. When  $c < \theta_3(\beta_3 - \beta_2) \left( r - \frac{r-r_0}{\beta_3} \right)$  and  $T \leq (1 - \beta_2) \left( r - \frac{r-r_0}{\beta_3} \right)$ , by considering (243) and (244), we have that  $\delta = \frac{r-r_0}{\beta_3}$ , and

$$\Pi_3^C = \Pi_3 - \left[ \theta_1(\beta_2 - \beta_1) \left( r - \frac{r-r_0}{\beta_3} \right) - c \right]. \quad (252)$$

This corresponds to Solution III.H.2.

3. When  $c < \frac{\theta_3(\beta_3 - \beta_2)T}{1 - \beta_2}$  and  $T > (1 - \beta_2) \left( r - \frac{r-r_0}{\beta_3} \right)$ , we further consider the following cases, which correspond to different scenarios in Solution III.H.3.

(a) when  $l \leq l_h$ , the optimal contract under Scenario II, i.e., (243), can be simplified into:

$$\delta = \min \left( r - \frac{c}{\theta_3(\beta_3 - \beta_2)}, r - \frac{r - \frac{r-r_0}{\beta_3} + lT}{1 + (1 - \beta_2)l} \right). \quad (253)$$

Therefore, consider the following two cases.

- i. when  $c < \frac{\theta_3(\beta_3 - \beta_2) \left[ r - \frac{r-r_0}{\beta_3} + lT \right]}{1 + (1 - \beta_2)l}$ , the optimal solution under Scenario II is  $\delta = r - \frac{r - \frac{r-r_0}{\beta_3} + lT}{1 + (1 - \beta_2)l}$ , and the corresponding payoff is

$$\Pi_3^C = \Pi_3 - \left[ \frac{\theta_1(\beta_2 - \beta_1) \left( r - \frac{r-r_0}{\beta_3} + lT \right)}{1 + (1 - \beta_2)l} - c \right] - \sum_{i=1}^2 \theta_i \beta_i l \left[ \frac{T - (1 - \beta_2) \left( r - \frac{r-r_0}{\beta_3} \right)}{1 + (1 - \beta_2)l} \right], \quad (254)$$

corresponding to Solution C.3.H.3(a).

- ii. when  $c \in \left[ \frac{\theta_3(\beta_3 - \beta_2) \left[ r - \frac{r - r_0}{\beta_3} + lT \right]}{1 + (1 - \beta_2)l}, \frac{\theta_1(\beta_2 - \beta_1)T}{1 - \beta_2} \right)$ ,  $\delta = r - \frac{c}{\theta_3(\beta_3 - \beta_2)}$ , and hence the supplier's payoff is:

$$\Pi_3^C = \Pi_3 - \frac{(\beta_2 - \bar{\beta})c}{\theta_3(\beta_3 - \beta_2)} - \sum_{i=1}^2 \theta_i \beta_i l \left[ T - \frac{(1 - \beta_2)c}{\theta_3(\beta_3 - \beta_2)} \right]. \quad (255)$$

This corresponds to Solution C.3.H.3(b).

- (b) when  $l > l_h$ , the solution in Scenario II follows (244). By comparing the four scenarios, we can see that the binding one is  $\delta = r - \frac{T}{1 - \beta_2}$ . In this case, the supplier avoids financing cost, and her payoff is:

$$\Pi_3^C = \Pi_3 - \left( \frac{\theta_3(\beta_3 - \beta_2)T}{1 - \beta_2} - c \right). \quad (256)$$

This corresponds to Solution C.3.H.3(c).  $\square$

**Proof of Lemma E.5.** In addition to the cancelation policies covered in Lemmas E.3 and E.4, cancelable contracts under which the insurer exerts effort, as summarized in Lemma B.1 and Lemma E.2, may induce the following three types of cancelation policies.

1. If the insurer cancels only at  $i = 2$ , which leads to  $j = 2$  and  $m = 2$  using the notation in Lemma E.2. In terms of the supplier's shipping decision, by applying Lemma 3, we can show that other the following scenarios are possible.

- (a) The supplier ships only at  $i = 1$ , which leads to  $k = 1$ .
- (b) The supplier ships at  $i = 1, 2$ , which leads to  $k = 2$ .

To see why other shipping policies are not possible, note that according to Lemma 3, the supplier's shipping policy is always a one threshold policy. Therefore, for the supplier to ship at any state, which is a necessary condition for the insurer to exert effort, the supplier must ship at  $i = 1$ . Depending whether she ships at  $i = 2$ , we have the above two scenarios. Now, it is clearly that the supplier will not ship at  $i = 3$ , because if she does, she will ship at all signals, which again violates the necessary condition for the insurer to exert effort. As such, only the above two scenarios are feasible. For the following scenarios of cancelation policy, the logic is similar and we omit the detail there.

2. If the insurer cancels only at  $i = 1, 2$ , which leads to  $j = 1$  and  $m = 2$ . In terms of the supplier's shipping decision, there are two possible scenarios.
  - (a) The supplier ships only at  $i = 1$ , which leads to  $k = 1$ .
  - (b) The supplier ships at  $i = 1, 2$ , which leads to  $k = 2$ .
3. If the insurer cancels at only  $i = 1$ , which leads to  $j = 1$  and  $m = 1$ , which also leads to  $k = 1$ . This means that the supplier ships at only  $i = 1$ .

Rearranging these scenarios based on the supplier's shipping policy, we arrive at the following two cases.

1. The supplier ships at  $i = 1$  (possibly uninsured). Under this shipping policy, the upper bound of the supplier's payoff is  $\Pi_2$ . By comparing this with the optimal contract in Lemmas E.3 and E.4, we note that:

- (a) when  $\beta_2 < \bar{\beta}$ , we further consider two cases.
- i. when  $c \geq \theta_1(\beta_2 - \beta_1) \max\left(r - \frac{r-r_0}{\beta_3}, \frac{T}{1-\beta_2}\right)$ , according to Lemma E.4 (Solution III.L.1), there exists a contract that can achieve the first-best payoff  $\Pi_3$ , which is greater than  $\Pi_2$ .
  - ii. when  $c < \theta_1(\beta_2 - \beta_1) \max\left(r - \frac{r-r_0}{\beta_3}, \frac{T}{1-\beta_2}\right)$ , we can verify that the solution in Lemma E.3 is feasible, and it leads to the payoff  $\Pi_2^C$  greater than or equal to the upper bound  $\Pi_2$ .
- (b) when  $\beta_2 \geq \bar{\beta}$ , we can verify that the solution in Lemma E.3 is feasible, and the corresponding payoff is greater than or equal to the upper bound  $\Pi_2$ .
2. The supplier ships at  $i = 1, 2$ , and always uninsured at  $i = 2$ . Under this shipping policy, the upper bound of the supplier's payoff is  $\Pi_3 - \theta_2\beta_2 lT$ . Similar to the previous case, we can show that such contract is (weakly) dominated by  $\Pi_2^C$  (in Lemma E.3) or  $\Pi_3^C$  (in Lemma E.4).

Combining the above two cases, we conclude that we do not need to consider cancelable contracts other than those studied in Lemmas E.3 and E.4.  $\square$

**Proof of Lemma E.6.** We first simplify this set of inequalities. First, we notice that as  $\frac{\theta_1\beta_1 + \theta_2\beta_2}{\theta_1 + \theta_2} < \bar{\beta}$ , given (116), (122) is redundant. Second, similar to the proof in Lemma E.4, (120) and (121) are redundant, and without loss of generality, we can set  $f = p$ . After consolidating all these simplifications, (115)–(122) become:

$$\max_{\delta \in [0, r], f} \Pi_3 - \sum_{i=1}^2 \theta_i L(r - f - \delta) - \left\{ \sum_{i=1}^2 \theta_i [f - \beta_i(r - \delta)] - c \right\}; \quad (257)$$

$$\text{s.t. } r_0 \leq r - \bar{\beta}[\delta + L(r - \delta - f)]; \quad (258)$$

$$f \leq \beta_3(r - \delta) - \frac{c}{\theta_3}; \quad (259)$$

$$f \geq \frac{c + \sum_{i=1}^2 \theta_i \beta_i(r - \delta)}{\theta_1 + \theta_2}; \quad (260)$$

$$f \geq \beta_2(r - \delta); \quad (261)$$

The second and third component corresponding represents the potential financing cost and rent surrounded to the insurer. We observe that for any given  $\delta$ , decreasing  $f$  improves the objective function. In addition, note that as  $f$  decreases, both (258) and (259) become less stringent. Therefore, at the optimal  $f$ , at least one of (260) and (261) is binding. By comparing the two conditions, we can see that the binding one depends on the magnitude of  $\delta$ . Specifically, by comparing the right hand side of (260) and (261), we note that

$$\frac{c + \sum_{i \leq 2} \theta_i \beta_i(r - \delta)}{\theta_1 + \theta_2} \geq \beta_2(r - \delta) \quad (262)$$

is equivalent to

$$\delta \geq r - \frac{c}{\theta_1(\beta_2 - \beta_1)}. \quad (263)$$

When this condition is satisfied, (260) is the binding constraint, i.e., the insurer does not extract rent. Otherwise, (261) is the binding constraint, and the insurer extracts rent. In the following, we analyze the optimal contract depending on which of the two constraints are binding.

**Scenario I** ( $\delta \geq r - \frac{c}{\theta_1(\beta_2 - \beta_1)}$ ): (260) is the binding constraint, and it can be re-written:

$$f = \frac{c + \sum_{i=1}^2 \theta_i \beta_i(r - \delta)}{\sum_{i=1}^2 \theta_i}, \quad (264)$$

and (257) – (261) can be further simplified to:

$$\max_{\delta \in [0, r]} \Pi_3 - \sum_{i=1}^2 \theta_i \beta_i L \left( \left[ 1 - \frac{\sum_{i=1}^2 \theta_i \beta_i}{\sum_{i=1}^2 \theta_i} \right] (r - \delta) - \frac{c}{\sum_{i=1}^2 \theta_i} \right) \quad (265)$$

$$\text{s.t. } \delta \leq r - \frac{c}{\theta_3(\beta_3 - \bar{\beta})} \quad (266)$$

$$\delta \geq r - \frac{c}{\theta_1(\beta_2 - \beta_1)} \quad (267)$$

$$\delta + L \left( \left[ 1 - \frac{\sum_{i=1}^2 \theta_i \beta_i}{\sum_{i=1}^2 \theta_i} \right] (r - \delta) - \frac{c}{\sum_{i=1}^2 \theta_i} \right) \leq \frac{r - r_0}{\bar{\beta}} \quad (268)$$

By comparing (266) and (267), we note that the two constraints can jointly hold if and only if  $\theta_3(\beta_3 - \bar{\beta}) \geq \theta_1(\beta_2 - \beta_1)$ , or equivalently,  $\beta_2 \leq \bar{\beta}$ . In other words, if  $\beta_2 > \bar{\beta}$ , there exists no cancelable contract under which the insurer does not extract rent with the specified cancelation and shipping policies. Therefore, in the following analysis of **Scenario I**, we should work under the condition that  $\beta_2 \leq \bar{\beta}$ .

Under this condition, we note that the objective function decreases in  $\delta$ . Therefore, the optimal solution corresponds to the smallest feasible  $\delta$ . Further note that both (266) and (268) are loosened as  $\delta$  decreases, hence, the optimal solution should satisfy:

$$\delta = \left( r - \frac{c}{\theta_1(\beta_2 - \beta_1)} \right)^+. \quad (269)$$

We can verify that under this deductible and  $\beta_2 \leq \bar{\beta}$ , (266) always holds. To check whether (268) holds under this contract, we further consider two scenarios, depending on whether  $\delta = 0$ , i.e.,  $r - \frac{c}{\theta_1(\beta_2 - \beta_1)} \leq 0$ .

**Scenario I.A:** For  $c \geq \theta_1(\beta_2 - \beta_1)r$ ,  $\delta = 0$ . We can also verify that (268) holds under all  $T$  that satisfies Assumption 2. Thus, the corresponding optimal contract is:

$$\delta = 0; \quad p = f = \frac{c + \sum_{i=1}^2 \theta_i \beta_i r}{\sum_{i=1}^2 \theta_i}. \quad (270)$$

And the supplier's payoff is  $\Pi_3$ . In other words, the supplier receives the full value of TCI.

**Scenario I.B:** For  $c < \theta_1(\beta_2 - \beta_1)r$ , the possible optimal solution, if feasible, is:

$$\delta = r - \frac{c}{\theta_1(\beta_2 - \beta_1)}; \quad p = f = \frac{\beta_2 c}{\theta_1(\beta_2 - \beta_1)}. \quad (271)$$

This solution is feasible if and only if it satisfies (268), or equivalently,

$$r - r_0 \geq \bar{\beta} \left[ r - \frac{c}{\theta_1(\beta_2 - \beta_1)} + L \left( \frac{(1 - \beta_2)c}{\theta_1(\beta_2 - \beta_1)} \right) \right]. \quad (272)$$

Note that if this inequality does not hold, then the optimization problem (265) – (268) is infeasible. In other words, there exists no solution in **Scenario I** under which (267) is binding. Thus, depending on whether the supplier can avoid financing cost, i.e.,  $T \leq \frac{(1 - \beta_2)c}{\theta_1(\beta_2 - \beta_1)}$ , we further consider two cases.

**Scenario I.B.a:** for  $T \leq \frac{(1 - \beta_2)c}{\theta_1(\beta_2 - \beta_1)}$ , or equivalently,

$$c \geq \frac{\theta_1(\beta_2 - \beta_1)}{(1 - \beta_2)} T, \quad (273)$$

the supplier can avoid financing cost. Under this condition, (272) holds if and only if:

$$c \geq \theta_1(\beta_2 - \beta_1) \left( r - \frac{r - r_0}{\bar{\beta}} \right), \quad (274)$$

which always holds as  $r_0 \leq (1 - \bar{\beta})r$  (Assumption 1). Thus, the contract in (271) leads to  $\Pi_3$  in this region.

**Scenario I.B.b:** for  $T \geq \frac{(1-\beta_2)c}{\theta_1(\beta_2-\beta_1)}$ , or equivalently,

$$c \leq \frac{\theta_1(\beta_2 - \beta_1)}{(1 - \beta_2)}T, \quad (275)$$

(272) can be re-written as:

$$c \geq \frac{\theta_1(\beta_2 - \beta_1) \left( r - \frac{r-r_0}{\bar{\beta}} + lT \right)}{1 + (1 - \beta_2)l}. \quad (276)$$

Note that (275) and (276) jointly hold if  $T \geq 0$ . Therefore, we have two cases:

1. When (276) holds, contract (271) is feasible, and the supplier's payoff is  $\Pi_u - \sum_{i=1}^2 \theta_i \beta_i l \left[ T - \frac{(1-\beta_2)c}{\theta_1(\beta_2-\beta_1)} \right]$ .
2. When  $c < \frac{\theta_1(\beta_2-\beta_1) \left( r - \frac{r-r_0}{\bar{\beta}} + lT \right)}{1 + (1-\beta_2)l}$ , no contract under **Scenario I** is feasible.

Combining Scenario I.A, Scenario I.B.a and Scenario I.B.b (two sub-cases), we summarize the optimal contract in Scenario I (for  $\beta_2 \leq \bar{\beta}$ ) as follows.

1. When  $c \geq \frac{\theta_1(\beta_2-\beta_1)T}{1-\beta_2}$ ,  $\Pi_3^U = \Pi_3$  under contract (270) or (271).
2. When  $c \in \left[ \frac{\theta_1(\beta_2-\beta_1) \left( r - \frac{r-r_0}{\bar{\beta}} + lT \right)}{1 + (1-\beta_2)l}, \frac{\theta_1(\beta_2-\beta_1)T}{1-\beta_2} \right)$ , the contract (271) is feasible, and

$$\Pi_3^U = \Pi_3 - \sum_{i=1}^2 \theta_i \beta_i l \left( T - \frac{(1-\beta_2)c}{\theta_1(\beta_2-\beta_1)} \right). \quad (277)$$

3. When  $c < \frac{\theta_1(\beta_2-\beta_1) \left( r - \frac{r-r_0}{\bar{\beta}} + lT \right)}{1 + (1-\beta_2)l}$ , no contract that satisfy  $\delta \geq r - \frac{c}{\theta_1(\beta_2-\beta_1)}$  is feasible.

**Scenario II** ( $\delta \leq r - \frac{c}{\theta_1(\beta_2-\beta_1)}$ ): (261) is binding. Thus, we have  $p = f = \beta_2(r - \delta)$ . Substituting the above expression of  $p$  and  $f$  into (257) – (261) leads to:

$$\max_{\delta \in [0, r]} \Pi_3 - \sum_{i=1}^2 \theta_i \beta_i l [T - (1 - \beta_2)(r - \delta)]^+ - [\theta_1(\beta_2 - \beta_1)(r - \delta) - c] \quad (278)$$

$$\text{s.t. } \delta \leq r - \frac{c}{\theta_3(\beta_3 - \beta_2)}; \quad (279)$$

$$\delta \leq r - \frac{c}{\theta_1(\beta_2 - \beta_1)}; \quad (280)$$

$$\delta \leq \frac{r - r_0}{\bar{\beta}} - \frac{l \left[ T - (1 - \beta_2) \left( r - \frac{r-r_0}{\bar{\beta}} \right) \right]}{1 + l(1 - \beta_2)}. \quad (281)$$

As above, the three components of the objective function are: the first-best benchmark  $\Pi_3$ , the expected financing cost, and the rent surrendered to the insurer. Note that the information rent,  $\theta_1(\beta_2 - \beta_1)(r - \delta) - c$ , decreases in  $\delta$ , while the financing cost is constant in  $\delta$  for  $\delta \leq r - \frac{T}{1-\beta_2}$ , and increasing in  $\delta$  for  $\delta > r - \frac{T}{1-\beta_2}$ . Combining these two forces, as  $\delta$  increases from zero, the financing cost initially remains at zero, and hence the objective function increases until  $\delta = r - \frac{T}{1-\beta_2}$ . For a greater  $\delta$ , the supplier incurs financing cost, and  $\frac{d\Pi}{d\delta} > 0$  if and only if  $l < l_h$  as defined in Lemma E.4. Therefore, the optimal  $\delta$  follows two cases depending whether  $l$  is greater than  $l_h$ .

1. For  $l \leq l_h$ , as  $\delta$  increases, the corresponding increase in financing cost is not as great as the decrease in information rent. Therefore, the optimal contract sets the deductible as high as possible, i.e. at the level that at least one of (279) – (281) is binding. Equivalently,

$$\delta = \min \left( r - \frac{c}{\theta_3(\beta_3 - \beta_2)}, r - \frac{c}{\theta_1(\beta_2 - \beta_1)}, r - \frac{r - \frac{r-r_0}{\bar{\beta}} + lT}{1 + l(1 - \beta_2)} \right). \quad (282)$$

2. For  $l > l_h$ , for  $\delta > r - \frac{T}{1-\beta_2}$ , as  $\delta$  increases, the corresponding increase in financing cost dominates the decrease in information rent. Therefore, the optimal deductible should be:

$$\delta = \min \left( r - \frac{T}{1-\beta_2}, r - \frac{c}{\theta_3(\beta_3 - \beta_2)}, r - \frac{c}{\theta_1(\beta_2 - \beta_1)}, r - \frac{r - \frac{r-r_0}{\beta} + lT}{1+l(1-\beta_2)} \right). \quad (283)$$

Combining the above two cases in **Scenario II** with the three cases in **Scenario I** that we summarize above, we can fully characterize the optimal contract and the corresponding payoff.

First, when  $\beta_2 \leq \bar{\beta}$  (Solution U.3.L): under this condition, (280) is tighter than (279). Depending on the range of  $c$ ,  $T$ , and  $l$ , we further consider the following cases.

1. When  $c \geq \frac{\theta_1(\beta_2 - \beta_1)T}{1-\beta_2}$ , according to Scenario I, the supplier can receive the full value of TCI. This corresponds to Solution U.3.L.1.
2. When  $c \in \left[ \frac{\theta_1(\beta_2 - \beta_1)(r - \frac{r-r_0}{\beta} + lT)}{1+(1-\beta_2)l}, \frac{\theta_1(\beta_2 - \beta_1)T}{(1-\beta_2)} \right)$ , Scenario I is feasible. Next, consider the following two cases, which correspond to the two cases in Solution U.3.L.2.
  - (a) when  $l \leq l_h$ , the optimal contract under Scenario II, i.e., (282), can be simplified into:

$$\delta = \min \left( r - \frac{c}{\theta_1(\beta_2 - \beta_1)}, r - \frac{r - \frac{r-r_0}{\beta} + lT}{1+(1-\beta_2)l} \right). \quad (284)$$

Consider the following two cases.

- i. When  $c \in \left[ \frac{\theta_1(\beta_2 - \beta_1)(r - \frac{r-r_0}{\beta} + lT)}{1+(1-\beta_2)l}, \frac{\theta_1(\beta_2 - \beta_1)T}{1-\beta_2} \right)$ , we can show that the optimal contract under Scenario II, i.e.,  $\delta = r - \frac{c}{\theta_1(\beta_2 - \beta_1)}$ , is the same as in Scenario I. Therefore, the supplier's payoff is the same as in (277).
- ii. When  $c < \frac{\theta_1(\beta_2 - \beta_1)(r - \frac{r-r_0}{\beta} + lT)}{1+(1-\beta_2)l}$ , the optimal solution under Scenario II is  $\delta = r - \frac{r - \frac{r-r_0}{\beta} + lT}{1+(1-\beta_2)l}$ , and the corresponding payoff, following (237), is:

$$\Pi_3^U = \Pi_3 + c - \frac{\theta_1(\beta_2 - \beta_1)(r - \frac{r-r_0}{\beta} + lT)}{1+(1-\beta_2)l} - \sum_{i=1}^2 \theta_i \beta_i l \left[ \frac{T - (1-\beta_2)(r - \frac{r-r_0}{\beta})}{1+(1-\beta_2)l} \right]. \quad (285)$$

With some algebra, we can show that this payoff is always lower than the supplier's payoff under Scenario I, i.e., (277).

Combining these two cases, we can show that for  $l \leq l_h$ , the optimal contract is  $\delta = r - \frac{c}{\theta_1(\beta_2 - \beta_1)}$ , and the supplier's payoff follows (277). This corresponds to Solution U.3.L.2(a) in the lemma.

- (b) when  $l > l_h$ , the solution in Scenario II follows (283). By comparing the four scenarios, we can see that the binding one is  $\delta = r - \frac{T}{1-\beta_2}$ , and

$$\Pi_3^U = \Pi_3 - \left[ \frac{\theta_1(\beta_2 - \beta_1)T}{1-\beta_2} - c \right], \quad (286)$$

which is greater than the the supplier's payoff under Scenario I as given by (277). Thus, the solution in Scenario II is optimal. This corresponds to Solution U.3.L.2(b).

3. When  $c < \frac{\theta_1(\beta_2 - \beta_1)(r - \frac{r-r_0}{\beta} + lT)}{1+(1-\beta_2)l}$ , Scenario I is infeasible. Therefore, we only need to consider the optimal solution in Scenario II. By considering (282) and (283), we have that  $\delta = \frac{r-r_0}{\beta} - \frac{l[T - (1-\beta_2)(r - \frac{r-r_0}{\beta})]}{1+l(1-\beta_2)}$ , and the supplier's payoff is:

$$\Pi_3^U = \Pi_3 - \left[ \frac{\theta_1(\beta_2 - \beta_1)(r - \frac{r-r_0}{\beta} + lT)}{1+(1-\beta_2)l} - c \right] - \frac{l(\theta_1\beta_1 + \theta_2\beta_2)[T - (1-\beta_2)(r - \frac{r-r_0}{\beta})]}{1+(1-\beta_2)l}. \quad (287)$$

This corresponds to Solution U.3.L.3.

Second, in the case with  $\beta_2 > \bar{\beta}$  (Solution U.3.H in the Lemma), the solution in Scenario I is infeasible. Therefore, we only need to consider the solution in Scenario II, as governed by (282) and (283). Further, (279) is tighter than (280). Depending on the range of  $c$ ,  $T$ , and  $l$ , we further consider the following cases.

1. When  $c \geq \frac{\theta_3(\beta_3 - \beta_2)T}{1 - \beta_2}$ , regardless of  $l$ , we have:  $\delta = r - \frac{c}{\theta_3(\beta_3 - \beta_2)}$ , and the supplier's payoff, following (278), is  $\Pi_3^U = \Pi_3 - \frac{(\beta_2 - \bar{\beta})c}{\theta_3(\beta_3 - \beta_2)}$ . This corresponds to Solution U.3.H.1.
2. When  $c < \frac{\theta_3(\beta_3 - \beta_2)T}{1 - \beta_2}$ , depending on  $l$ , we consider the following two scenarios.
  - (a) When  $l < l_h$ , the optimal contract under Scenario II, i.e., (282), can be simplified into:

$$\delta = \min \left( r - \frac{c}{\theta_3(\beta_3 - \beta_2)}, r - \frac{r - \frac{r - r_0}{\bar{\beta}} + lT}{1 + (1 - \beta_2)l} \right). \quad (288)$$

Therefore, consider the following two cases.

- i. when  $c \in \left[ \frac{\theta_3(\beta_3 - \beta_2) \left[ r - \frac{r - r_0}{\bar{\beta}} + lT \right]}{1 + (1 - \beta_2)l}, \frac{\theta_1(\beta_2 - \beta_1)T}{1 - \beta_2} \right)$ ,  $\delta = r - \frac{c}{\theta_3(\beta_3 - \beta_2)}$ , and hence the supplier's payoff is:

$$\Pi_3^U = \Pi_3 - \frac{(\beta_2 - \bar{\beta})c}{\theta_3(\beta_3 - \beta_2)} - \sum_{i=1}^2 \theta_i \beta_i l \left[ T - \frac{(1 - \beta_2)c}{\theta_3(\beta_3 - \beta_2)} \right]. \quad (289)$$

This corresponds to Solution U.3.H.2(a).

- ii. When  $c < \frac{\theta_3(\beta_3 - \beta_2) \left[ r - \frac{r - r_0}{\bar{\beta}} + lT \right]}{1 + (1 - \beta_2)l}$ , the optimal solution under Scenario II is  $\delta = r - \frac{r - \frac{r - r_0}{\bar{\beta}} + lT}{1 + (1 - \beta_2)l}$ , and the corresponding payoff is

$$\Pi_3^U = \Pi_3 - \left[ \frac{\theta_1(\beta_2 - \beta_1) \left( r - \frac{r - r_0}{\bar{\beta}} + lT \right)}{1 + (1 - \beta_2)l} - c \right] - \sum_{i=1}^2 \theta_i \beta_i l \left[ \frac{T - (1 - \beta_2) \left( r - \frac{r - r_0}{\bar{\beta}} \right)}{1 + (1 - \beta_2)l} \right], \quad (290)$$

corresponding to Solution U.3.H.2(b).

- (b) When  $l \geq l_h$ , we should have  $\delta = r - \frac{T}{1 - \beta_2}$ , and  $\Pi_3^U = \Pi_3 - \left( \frac{\theta_3(\beta_3 - \beta_2)T}{1 - \beta_2} - c \right)$ . This corresponds to Solution U.3.H.2(c).  $\square$