Cancelability in Trade Credit Insurance

S. Alex Yang
Management Science and Operations, London Business School, Regent's Park, London NW1 4SA, United Kingdom, sayang@london.edu

Nitin Bakshi
David Eccles School of Business, The University of Utah, Salt Lake City, Utah, 84112 nitin.bakshi@eccles.utah.edu

Christopher J. Chen
Management Science and Operations, London Business School, Regent's Park, London NW1 4SA, United Kingdom, cchen@london.edu

Trade credit insurance (TCI) is a risk management tool commonly used by suppliers to guarantee against payment default by buyers. Unlike insurance policies in other sectors, TCI policies often allow the insurer to cancel this "guarantee" during the insured period. A guarantee that can be canceled is both paradoxical and controversial. This paper explores the role of *cancelability* in TCI and its operational implications. Using a game-theoretic model to capture the strategic interaction between insurer and supplier, we find that the utility of cancelability in TCI is linked to the two roles that the insurer plays in this setting: The (cash flow) *smoothing role* (smoothing the supplier's cash flows), and the *monitoring role* (tracking the buyer's *continued* creditworthiness during the insured period, which enables the supplier to make more efficient operational decisions regarding whether to ship goods to the buyer on credit). Non-cancelable contracts are static (determined ex ante) and rely on the deductible to implement these two roles, which results in a conflict: A high deductible inhibits the smoothing role while a low deductible weakens the insurer's incentive to fulfill the monitoring role. In contrast, cancelable contracts are dynamic: The insurer can cancel coverage *after* acquiring new information about the buyer's default risk. The right to cancel coverage ensures that information acquired through monitoring 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 of cancelable contracts, we find conditions when they induce the insurer to exercise the cancelation option too aggressively; thereby restoring a preference for non-cancelable contracts. Our findings help explain the historical dominance of cancelable contracts in TCI, and they also offer insight into the recent industry trend of offering non-cancelable TCI coverage.

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

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

---

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 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. TCI can be used to insure a single supplier-buyer transaction, or the entire trade between a supplier and a predetermined set of buyers for a fixed duration (typically a year).[1] 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 2014, TCI covered €2.2 trillion of exposure globally (International Credit Insurance and Surety Association 2015).

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 (Jones 2010). The notion of a "cancelable guarantee" seems paradoxical: In the context of health insurance, for example, the insurer cannot cancel coverage mid-term simply because the insured's health deteriorates.[2] Yet, the fact that cancelable TCI has been the norm in practice contravenes this rationale.

Not only are cancelable contracts the norm in TCI, it is also fairly common for insurers to exercise their cancelation option. 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' ability to trade (Kollewe 2009). It is estimated that from 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.[3] Thus, exercise of the cancelation option is often controversial 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

[1] In the paper, we focus on the single transaction case for simplicity.

[2] Note that TCI may be canceled at a discretionary time; this is distinct from the periodic decision of whether or not to renew a policy, which is commonplace in insurance settings.

[3] We refer to a decision as being *efficient* if it is consistent with the central planner's decision, or equivalently, the first-best decision.

friends who don't go into enough detail, make unilateral decisions at short notice and jeopardize the futures of businesses" (Stacey 2009).

In response to these concerns about the cancelation of coverage, the TCI industry devised and promoted the option of non-cancelable coverage (AIG 2013). The industry touted this as a significant innovation that would help restore the efficiency of shipping decisions. This begs the question that if non-cancelable insurance is the panacea, why the TCI industry has lagged behind its insurance industry peers in offering this variant. Will non-cancelable TCI become the new industry norm? Given the high stakes, such questions have received considerable attention lately 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) Why are cancelable contracts the dominant form in TCI but not in other insurance settings? 3) What limitations of the cancelable contract may account for the emergence of non-cancelable contracts?

To answer these questions, we develop and analyze a game-theoretic model that captures the strategic interactions between the supplier and the insurer. In our model, a risky buyer places an order on trade credit 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. The insurer can exert costly yet unverifiable monitoring effort to obtain updated information about the buyer's default risk, which is shared with the supplier. This feature of the model captures the fact that, in contrast to other forms of insurance, 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 information about the buyer's evolving default risk (Jones 2010). Based on the updated assessment of the buyer's risk, the supplier may revisit her decision to ship the order.

By comparing two benchmark scenarios – the first-best benchmark and the no-insurance benchmark, we find that TCI is meant to fulfill two roles. First, on the financial side, TCI is meant to smoothen the supplier's cash flow across different possible realizations of buyer's risk, and thereby mitigate the negative 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. We refer to this as the *monitoring role* of TCI. We find that fulfilling the monitoring role of TCI requires both, that the insurer has the incentive to obtain updated information, and that the supplier is willing to make efficient operational 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 commonly seen in practice: non-cancelable and cancelable contracts. Under the non-cancelable contract, the norm in other insurance settings, the supplier's revenue (i.e., buyer's payment) from an order (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 at its discretion. We find that, as a *static* contract (entirely determined ex-ante), a non-cancelable contract with a deductible is inherently limited in its ability to overcome the conflicts of interest that arise in fulfilling 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 then reduces the insurer's incentive to exert monitoring effort, thus weakening the monitoring role of TCI. On the other hand, a high deductible has two potential drawbacks. First, it exposes the supplier to higher financing costs, compromising the smoothing role of TCI. Second, a high deductible may reduce the insurer's exposure to an extent that it may be discouraged from investing in monitoring.

In contrast, cancelable contracts are endowed with a *dynamic* capability (the option to cancel coverage) that is able to incorporate the insurer's updated information to appropriately influence the supplier's shipping decision. In particular, the insurer is now motivated to monitor because on learning that the buyer is overly risky, it can deter the supplier from shipping by exercising the option to cancel, without resorting to a high deductible. As such, it often allows the contract to fully realize the smoothing value of TCI as well. These dynamics explain why cancelable insurance contracts, which seem paradoxical at first glance, have long prevailed in the TCI industry.

Although the cancelation option often allows cancelable contracts to fulfill both roles of TCI, 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. We find that over-cancelation occurs 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, non-cancelable contracts may be preferred, as they serve as a commitment by the insurer to provide coverage. This result resonates with the controversy regarding the insurers' cancelation actions, and offers an explanation for the emergence of non-cancelable coverage following the recent financial crisis. Finally, we identify that contracts that combine the advantages of cancelable and non-cancelable features can further enhance the value of TCI.

To the best of our knowledge, our paper is the first to study TCI contracts. We identify and model a novel feature of the TCI setting – the monitoring role of TCI. Analyzing this feature enables us to offer a theoretical underpinning for cancelability in TCI. We find that the dynamic nature of cancelable contracts is beneficial in mitigating the incentive concerns linked to the monitoring role. Contracts that strike a balance between the dynamic flexibility in cancelable contracts and the commitment value under non-cancelable contracts may further enhance the value of TCI.

The rest of the paper is organized as follows. In §2, we summarize the relationship of our paper to the literature. In Section 3, we lay out the model. We characterize the dual roles of TCI in §4. In §5 and 6, respectively, we describe the limitation of non-cancelable contracts, and the advantage of cancelable contracts in the TCI setting. This is followed by §7, in which we identify mechanisms to mitigate the risk of over-cancelation. We conclude the paper in §8. All proofs are in the Appendices, which also include a list of notation used.

2. Related literature

Our work is related to two major streams of literature: Insurance; and the interface of operations management, finance, and risk management. We discuss these in turn. Thereafter, we also connect our work to the literature on double moral hazard; ours is a special case of double moral hazard which has not been studied before.

The main focus in the insurance literature has been on the implications of asymmetric information, which manifests either in the form of adverse selection (Rothschild and Stiglitz 1976) or moral hazard (Shavell 1979). The two are distinguished by the timing of informational asymmetry. In adverse selection problems, the insured party has private information at the time of contracting; hence, the primary goal of the optimal insurance contract is to "screen the insured party's hidden information.[4] In moral hazard problems, in contrast, the insured and insurer are symmetrically informed at the time of contracting; the asymmetric information arises from the insured party's hidden (typically unobservable) actions taken after entering into the contract. An example of such a hidden action would be the (typically inadequate) precautionary effort undertaken by an insured party to mitigate the risk that is being insured. The optimal insurance contract is designed to induce more efficient actions and involves the use of a deductible. Recently, Winter (2013) provided an excellent overview of the literature on insurance with moral hazard. Our work, which also focuses on optimal contracts under moral hazard, contributes to the 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 moral hazard associated with the supplier's shipping decision, but also the moral hazard associated with insurer's monitoring effort. In this setting, we find that a traditional contract (a non-cancelable contract with only a

[4] Screening involves the insured party self-selecting into a contract from among a menu of contracts offered by the insurer, so as to truthfully reveal the private information.

deductible) in general fails to completely mitigate these moral hazards, when the insurer's monitoring cost is relatively high. Instead, granting the insurer a cancelation option often improves the contract performance, rationalizing the dominance of cancelable contracts in TCI.

Second, and relatedly, depending on whether the hidden action takes place before or after the uncertainty is resolved, 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 following an adverse health event, when expenses are covered by insurance (Zeckhauser 1970, Ma and Riordan 2002). Our paper adds a novel dimension to the insurance literature by encompassing both ex-ante moral hazard (the insurer's monitoring effort) and ex-post moral hazard (the supplier's shipping decision). The resulting dynamics are qualitatively different to those studied in the literature and warrant the use of the cancelability feature in TCI contracts.

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 associated with the tendency of the insurer to over cancel, i.e., cancel the insurance coverage and deter the supplier from shipping when it is efficient to ship. This moral hazard, which is absent in a non-cancelable contract, helps explain when and why the non-cancelable contract can be the preferred contract form.

Our work is also related to a fast-growing field: The interface of operations management, finance, and risk management. See Kouvelis et al. (2011) for an overview of related topics. Within this stream, our work is most related to the papers on the interaction between insurance and operations. Dong and Tomlin (2012) and Dong et al. (2015) characterize how business interruption (BI) insurance interact with firms' inventory policies. Serpa and Krishnan (2015) also focus on BI insurance, and they highlight its strategic role in mitigating free riding by inducing both supply chain parties to exert effort. We complement the above papers through our focus on trade credit insurance, another sector of insurance closely related to supply chain operations. In particular, we capture the strategic interaction between the insurer and the supplier, and study its implications for the optimal contract forms. In addition, this work is related to papers on the operational benefit of financial hedging, a prominent financial risk management tool (Gaur and Seshadri 2005, Ding et al. 2007, Kouvelis et al. 2013, Turcic et al. 2015), and those on supply chain finance (Babich and Tang 2012, Kouvelis and Zhao 2012, Chod 2015, Peura et al. 2016, Yang and Birge 2009), as well as recent papers on the impact of operational flexibility on financial contracting (Iancu et al. 2015).

Finally, since the actions of the both the insurer and the supplier are vulnerable to moral hazard, our paper is conceptually related to the literature on double moral hazard, which has been studied in economics (e.g., Bhattacharyya and Lafontaine 1995), and in operations in the context of collaborative production (Corbett et al. 2005), service (Roels et al. 2010), and maintenance (Jain et al. 2013). In particular, the sequential nature of the two moral hazards in our paper is similar to that in warranties (Cooper and Ross 1985, Emons 1988). In general, this literature highlights the benefit of performance-based contracts (PBC) and share contracts. These contracts are static in nature and do not require or possess the ability to dynamically incorporate any information updates. In contrast, in our problem, the monitoring effort of the insurer results in informational gains; consequently, we require a contract form which dynamically incorporates the monitoring-generated update, in order to appropriately influence the subsequent shipping decision of the supplier. This dynamic 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 default risk. 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 chance that the buyer may default on the payment. For expositional brevity, we assume that upon default, the supplier receives no money from the buyer.

To protect itself against buyer 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 $r_0 < r$. We let $\beta^{FB} = \frac{r-r_0}{r}$ be the threshold probability of the buyer's default such that the expected revenue from selling to the buyer equals the supplier's outside option, i.e., $(1-\beta^{FB})r = r_0$.

The supplier's objective is to maximize her (expected) payoff, which includes the incoming revenue and claim payments, and the outgoing insurance premium and financing-related costs. Without loss of generality, we normalize the risk-free interest rate to zero. We leave the details of how the insurance premium and claim payment are determined to Section 3.3, but characterize the supplier's financing costs as follows. As documented in the finance literature (Kaplan and Zingales 1997, Pulvino 1998, 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) or information asymmetry. 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. For example, the firm may have existing debt in place T. If the firm's net cash flow by the end of the period is lower than T, then to repay its debt, the firm must sell parts of its assets at a discount, as captured by l in the model, or equivalently, the lender may liquidate the supplier's collateral at a discount (Kouvelis and Zhao 2011). As such, $L(x)$ captures the total transaction cost associated with the shortfall in cash.[5] Finally, we assume that despite the financial constraint T, the firm has sufficient short-term liquidity to cover the insurance premium in the midst of the period.

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 and operates in a competitive insurance market (see, for example, Winter 2013). Therefore, the insurer is willing to offer the insurance product as long as the premium covers his expected cost.[6]

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 monitoring effort at a cost $c^E > 0$ to obtain updated information about the buyer's risk. This assumption reflects that the insurer not only assesses the buyer's credit risk before entering into the contract but may also invest in monitoring the buyer's *continued* creditworthiness *after* the insurance is in place. This feature of our setting is novel because TCI covers the buyer's default risk, which is not internal to the insured party (supplier) and is evolving. Thus, the supplier often does not have cost-effective access to all the relevant information about this risk. In fact, according to Jones (2010), "the essential value of trade credit insurance is that it provides . . . valuable market intelligence on the financial viability of the supplier's customers. This is achieved by (the insurer)

[5] Alternatively, $L(x)$ can also be seen as an abstraction of the supplier's opportunity cost: assume that at the end of the period, the supplier may face an investment opportunity, which allows him to earn investment return l for investment with a size up to T.

[6] As shown later, under certain conditions, the agreed-upon premium may be higher than the insurer's expected cost, as the supplier needs to induce the insurer to exert monitoring effort. Furthermore, our main insights remain unchanged if we allow the insurer to have a strictly positive reservation profit. In addition, we show in Online Appendix F that the main insight of the paper remains unchanged when the insurer incurs a transaction cost related to processing of a claim, which is proportional to the size of the claim, as modeled in Dong and Tomlin (2012).

gathering information about the buyer(s) from a variety of sources." Such information may reflect worsening political or geographical risk, e.g., the debt crisis in Greece (Freely 2012), or the buyer's severely deteriorating financial situation, e.g., large scale store closures by Circuit City (Birchall 2008). Upon exerting effort, the insurer shares the obtained information with the supplier.[7]

Following common practice in the TCI industry (International Credit Insurance & Surety Association 2015), we assume that all possible signals that the insurer may receive about the buyer's continued creditworthiness can be classified into N groups, depending on their associated risk level. We denote the default probability associated with group i to be β_i, and the probability of obtaining a signal for group i to be θ_i, where $0 \leq \beta_1 < \beta_2 < \ldots < \beta_N \leq 1$ and $\sum_i \theta_i = 1$. Correspondingly, the prior expected value of the buyer's default probability is $\bar{\beta} = \sum_i \beta_i \theta_i$. For tractability, we focus on the case where $N = 3$ in the paper.[8] This case captures the essence of information updating by classifying the risk level associated with a signal to be low, medium, or high. Specifically, a signal corresponding to the low risk group ($i = 1$) reflects that the buyer is operating as usual with its default risk under control, i.e., no risk-aggravating events were discovered by the insurer. A signal embodying medium risk ($i = 2$) captures the scenario in which although there are some worrying signs about the buyer's creditworthiness, it is not immediately apparent whether shipping on credit is efficient. Finally, a signal within the high risk group ($i = 3$) shows strong evidence suggesting that a credit sale is overly risky. Relating the corresponding default probability β_i with β^{FB}, we say that the shipping decision is *efficient* if and only if the supplier ships under all signals i with $\beta_i \leq \beta^{FB}$.

3.3. TCI contracts

Motivated by industry practice (AIG 2013, Thomas 2013), we mainly focus on the following two types of TCI contracts, with the corresponding sequence of events is depicted in Figure 1.[9]

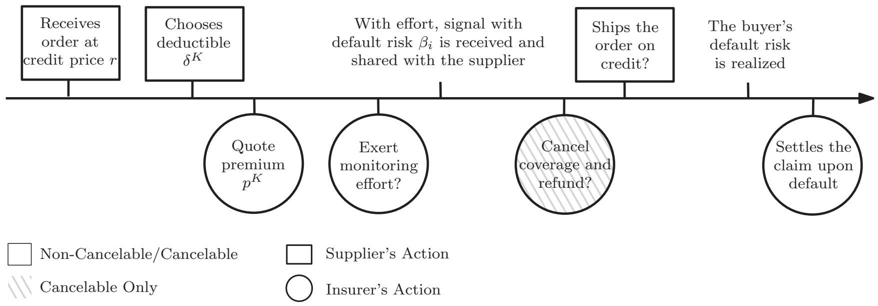
- Non-cancelable TCI: Under a non-cancelable contract, the supplier selects her desired deductible δ^{NC} and the insurer responds by quoting premium p^{NC}. After the contract is signed,

[7] We abstract away from the possibility of the insurer strategically manipulating information because that is consistent with our understanding of practice (e.g., the insurer's and supplier's IT systems are partially connected), and moreover, analysis presented in Online Appendix G suggests that the insurer does not have the incentive to misrepresent. Thus, we are able to streamline exposition and focus instead on the moral hazard associated with the insurer fulfilling his monitoring role - the issue that we believe is of primary importance.

[8] As shown later, our model formulation and most analytical results apply to the case with arbitrary N. Numerical results presented in Online Appendix E further confirm that the main insights of the paper remain unchanged for general N.

[9] In Section 7, we introduce two additional types of contracts: *hybrid contract* and cancelable contract with *cancelation penalty*. Note that while we allow 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 signal. 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. In addition, as in the standard moral hazard models, we assume that the insurer's monitoring effort is unverifiable and hence cannot be contracted directly.

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



Notes. Superscript K in p^K and δ^K represents the contract type, NC for non-cancelable, and C for cancelable.

the supplier pays p^{NC} to the insurer, and the insurer may choose to exert monitoring effort at a cost $c^E > 0$ 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 $r - \delta^{NC}$ 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 the premium p^C and the deductible δ^C, but also a refund of the premium $f^C \in [0, p^C]$. 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^C and removes his exposure to the buyer's credit risk. If he does not cancel, the insurer pays the supplier $r - \delta^C$ if the buyer defaults.

To avoid uninteresting cases, we make the following assumptions regarding the buyer's default risk and the supplier's financial constraint T.

Assumption 1. $\beta_N > \beta^{FB} > \bar{\beta}$.

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

Assumption 1 has two implications: First, the buyer is *a priori* creditworthy, i.e. without updated information, shipping to the credit buyer is more profitable than the outside option ($(1-\bar{\beta})r > r_0$); and second, the outside option is more valuable than shipping to the most risky buyer ($r_0 > (1-\beta_N)r$). Assumption 2 guarantees that the supplier does not incur financing costs unless she ships to a buyer who later defaults. This removes the uninteresting case where the supplier is so financially constrained that she incurs financing costs solely due to insurance premium.[10]

[10] As shown in Lemma C.1, the insurance premium is always less than $(r - r_0)$. Therefore, Assumption 2 ensures that when the supplier ships to her outside option, her net cash flow $(r_0 - (r - r_0))$ is always sufficient to avoid financing costs.

4. The dual roles of TCI and its potential value

Before analyzing the different TCI contracts, we establish two benchmarks – the first-best benchmark and the no-insurance benchmark, which allow us to identify the two roles TCI is meant to play, and then quantify the potential economic value of TCI.

4.1. The first-best benchmark

Under the first-best benchmark, the supplier's and insurer's actions are both controlled by a central decision-maker whose objective is to maximize the sum of the two parties' payoffs. By removing any possible agency issues, this benchmark achieves the best possible outcome.

LEMMA 1. *Let* $C_i^E := r\sum_{j=i}^N \theta_j(\beta_j - \beta^{FB})$, $\bar{C}^E := \max_{i\geq 2} C_i^E$, $\Pi^{NE} := (1-\bar{\beta})r$, *and* $\Pi_i^E := \Pi^{NE} + C_i^E - c^E$. *Under the first-best benchmark,*

1. *for* $c^E \leq \bar{C}^E$, *the insurer exerts effort and the supplier ships if and only if the observed signal* i *satisfies* $\beta_i \leq \beta^{FB}$. *The corresponding payoff is* $\Pi^E := \max_i \Pi_i^E = \Pi^{NE} + \bar{C}^E - c^E$;
2. *for* $c^E > \bar{C}^E$, *the insurer does not exert effort and the supplier always ships the order. The corresponding payoff is* Π^{NE}.

Lemma 1 shows that, intuitively, monitoring becomes more valuable when the monitoring costs (c^E) are low. Thus, to avoid trivial cases where exerting effort is not efficient even in the absence of agency issues, we focus our analysis on regions where $c^E \leq \bar{C}^E$ for the rest of the paper.

Further, as the supplier's shipping decision is efficient under the first-best benchmark, the option to cancel shipping, as enabled by monitoring, is more valuable when the outside option (r_0) is more attractive. Relatedly, as we show later, due to various incentive issues arising under the decentralized setting, the supplier may over-ship (ship at i with $\beta_i > \beta^{FB}$) or under ship (does not ship at i with $\beta_i < \beta^{FB}$). We will show how different TCI contracts can correct such a tendency and restore an efficient shipping decision.

4.2. The no-insurance benchmark

The second benchmark that we consider is the no-insurance benchmark, i.e., the supplier does not have access to any TCI insurance product.

LEMMA 2. *Without insurance,*

1. *for* $\bar{\beta} \leq \frac{r-r_0}{r+lT}$, *the supplier ships the order and her payoff is* $\Pi^{NI} = \Pi^{NE} - l\bar{\beta}T$;
2. *for* $\bar{\beta} > \frac{r-r_0}{r+lT}$, *the supplier does not ship and her payoff is* $\Pi^{NI} = r_0$.

Two observations are notable. First, without updated information, the supplier has to rely on her prior belief when making her shipping decision. Second, financing costs may harm the supplier from two potential channels: they may either directly lower the the supplier's payoff by $l\bar{\beta}T$, or discourage the supplier from shipping. Indeed, without insurance, the maximum default risk at which the supplier ships the order decreases from β^{FB} to $\frac{r-r_0}{r+lT}$. Clearly, both the financial loss and operational distortion are more pronounced when financing becomes more expensive (larger l) or the supplier is more financially constrained (larger T).

4.3. Potential value of TCI

We define the potential value of TCI as the difference between the first-best benchmark Π^E and the no-insurance benchmark $\Pi^{NI} = \max(\Pi^{NE} - l\bar{\beta}T, r_0)$. The difference is due to the dual roles that TCI plays. On the one hand, like other forms of insurance, TCI smoothes the insured firm's cash flow and lowers the negative impact of the buyer's default risk in this case – the (cash flow) *smoothing* role of TCI. The potential value of this role is captured by the difference between Π^{NE} (insurance without updated information) and Π^{NI} (no insurance). Clearly, this value increases as the financing friction (l or T) increases or when the buyer becomes ex-ante riskier (larger $\bar{\beta}$).

On the other hand, TCI also plays a *monitoring* role, which is absent in other insurance sectors. Specifically, by exerting costly effort, the insurer obtains updated information about the buyer's default risk, which enables the supplier to make more efficient shipping decisions. The potential value of this role is captured by the difference between Π^E (insurance with updated information) and Π^{NE}.

While the potential value of both roles of TCI is fully realized under a centralized setting (the first-best benchmark), 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.

5. Limitations of non-cancelable contracts

To fully understand the unique features of TCI, we start our analysis by examining the performance of non-cancelable contracts, which are the norm in other insurance sectors. In the rest of this section, we present our analysis in an order consistent with backward induction: We start with the supplier's shipping decision (§5.1), followed by the insurer's decision to exert monitoring effort (§5.2), and finally discuss the optimal contract and its limitations (§5.3 and §5.4).

5.1. The supplier's shipping decision

After entering into a contract with premium p^{NC} and deductible δ^{NC}, the supplier makes her shipping decision based on the most updated estimate of the buyer's default risk β, which is

β_i if the insurer exerts effort and obtains a signal associated with group i, or equals the prior expectation of default risk $\bar{\beta}$, if not. Under β, if the supplier ships the order, her expected payoff is $(1-\beta)r + \beta\,[r - \delta^{NC} - L(r - \delta^{NC} - p^{NC})]$, where $L(r - \delta^{NC} - p^{NC})$ is the financing cost in the event of the buyer defaulting. If she does not ship, her payoff is simply her outside option r_o. Note that even though the premium p^{NC} is sunk when the supplier makes her shipping decision, it still indirectly influences the supplier's shipping decision since a higher premium increases her financing cost.

By comparing the above two payoffs, the supplier ships the order if and only if the payoff from shipping exceeds her outside option, i.e. $r - \beta\,(\delta^{NC} + L(r - \delta^{NC} - p^{NC})) \geq r_0$, or equivalently, $\beta \leq \beta^{NC}$,[11] where

$$\beta^{NC} := \frac{r - r_0}{\delta^{NC} + L(r - \delta^{NC} - p^{NC})}. \tag{1}$$

This condition is consistent with the intuition that the supplier is more willing to ship when facing a lower deductible or premium.

5.2. The insurer's decision to exert monitoring effort

As mentioned earlier, different from other insurance settings, the TCI insurer may play an active monitoring role after the parties enter the insurance contract. Under contract (p^{NC}, δ^{NC}), the insurer anticipates the supplier's shipping decision as depicted above, and then decides whether to exert monitoring effort based on his own incentive compatibility (IC) and participation (IR) constraints.[12]

Lemma 3. *Under (p^{NC}, δ^{NC}), the insurer exerts monitoring effort if and only if all of the following three conditions are satisfied:*

$$\beta^{NC} \geq \bar{\beta}; \tag{NC-IC1}$$

$$\bar{\beta}(r - \delta^{NC}) \geq c^E + (r - \delta^{NC}) \sum_{i \leq i^{NC}} \theta_i \beta_i; \tag{NC-IC2}$$

$$p^{NC} \geq c^E + (r - \delta^{NC}) \sum_{i \leq i^{NC}} \theta_i \beta_i; \tag{NC-IR}$$

where $i^{NC} = \max\{i : \beta_i \leq \beta^{NC}\}$.

[11] When equality holds, the supplier is in fact indifferent in terms of shipping or not. In the following analysis, we adhere to the convention that at equality, the supplier acts in favor of the insurer's payoff. Since all functions are continuous, we can adjust contract parameters by an arbitrarily small amount to break the tie. Similarly, if the insurer is indifferent when making his decisions, he acts in favor of the supplier's payoff.

[12] For our analysis, we adopt the principal-agent framework, which is standard in the treatment of insurance problems with moral hazard. Under the assumption that the insurance market is perfectly competitive, we model the insurer as the agent and the supplier as the principal (e.g., see §9.2 in Winter 2013). Further note that, different from the traditional insurance literature, our model captures double moral hazard. As such, our principal-agent treatment also includes the insurer's IC constraints, which is absent in the classic insurance models.

The three conditions capture the intrinsic connection between the insurer's moral hazard and the supplier's shipping decision under insurance (implicit in the definition of i^{NC}, which is defined as the highest signal group i under which the supplier ships). (NC-IC1) and (NC-IC2) are the insurer's IC constraints. Specifically, for (NC-IC1), note that if the insurer does not exert effort, and hence has no updated signal, the supplier reacts according to the prior default risk $\bar{\beta}$. If $\bar{\beta} > \beta^{NC}$, the supplier does not ship, and hence, the cost to the insurer is zero, which is clearly less than the insurer's total cost under effort. Therefore, the insurer exerts effort only if, under the contract, the supplier ships at $\bar{\beta}$, i.e. $\beta^{NC} \geq \bar{\beta}$. In addition, (NC-IC2) states that the insurer's total cost without exerting effort, i.e., the expected claim payment when the supplier always ships under the prior expectation $\bar{\beta}$, is greater than his total cost when exerting effort, which is equal to the effort cost c^E plus the expected claim payment when the supplier ships for β_is that are no greater than β^{NC}. Finally, the insurer's participation constraint (NC-IR) states that the premium p^{NC} must cover his total expected cost.

5.3. The optimal non-cancelable contract without the insurer's effort

Now that we understand both parties' agency problems under a given non-cancelable contract, we proceed to characterize the optimal contract terms by comparing the ones that induce the insurer to monitor and those that do not.

LEMMA 4. *Among all insurance contracts (p^{NC}, δ^{NC}) that do not induce the insurer's effort, the one with $p^{NC} = p^{NE} := \bar{\beta}r$ and $\delta^{NC} = \delta^{NE} := 0$ is (weakly) dominating. Under this contract, the supplier always ships and her expected payoff is Π^{NE}.*

Comparing Lemma 4 with Lemmas 1 and 2, we note that while not inducing the insurer to exert effort, the above contract fully recovers the smoothing value of TCI. Relatedly, deductible becomes unnecessary. This is because in our model, deductible is used to mitigate both parties' moral hazards. Without the insurer's effort, the supplier's moral hazard, i.e., inefficient shipping decision, becomes irrelevant due to no information updating, deeming deductible redundant.

5.4. The optimal non-cancelable contract with the insurer's effort

While the contract in Lemma 4 recovers the smoothing value of TCI, it fails to unlock the monitoring value. In this section, we determine which contract, among the ones that induce the insurer's effort (i.e., (p^{NC}, δ^{NC}) that satisfy (NC-IC1) – (NC-IR) in Lemma 3) is the most beneficial to the supplier. After incorporating her optimal shipping decision under this contract, the supplier's objective is as follows.[13]

[13] For technical convenience, in our model, we assume the supplier, as the principal, chooses the premium, subject to the insurer's (the agent) IC and IR constraint. Note that even though the insurer is the party who quotes the premium p^{NC}, our model formulation is mathematically equivalent because the insurer operates in a competitive market, and thus he simply quotes the premium that satisfies his IC and IR constraints. The same approach is also used in the literature Winter (2013).

$$\max_{p^{NC},\delta^{NC}\in[0,r]} \sum_{i\leq i^{NC}} \theta_i\{(1-\beta_i)r+\beta_i[r-\delta^{NC}-L(r-\delta^{NC}-p^{NC})]\}+\sum_{i>i^{NC}}\theta_i r_0 - p^{NC}. \quad \text{(NC-OBJ)}$$

As shown, the supplier's expected payoff consists of three parts: the insurance premium p^{NC}, her revenue when she does not ship ($i > i^{NC}$), and her expected revenue when she ships ($i \leq i^{NC}$). 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 $\beta_i(r-\delta^{NC})$ as well as her expected financing cost $\beta_i L(r-\delta^{NC}-p^{NC})$ if the buyer defaults.

By solving (NC-OBJ) subject to (NC-IC1)–(NC-IR), and comparing the optimal solution with the contract that does not induce the insurer effort in Lemma 4, we can establish the optimal non-cancelable contract. In the following, we characterize the optimal contract and the parties' corresponding actions depending on whether the first-best benchmark can be achieved (Proposition 1) or not (Proposition C.1).

Proposition 1. *Let* $i^{FB} = \min\{i : \beta_i > \beta^{FB}\}$, $C_i^U := \sum_{j\geq i}\theta_j\beta_j\left(r-\frac{r-r_0}{\beta_i}\right)$, *and* $\tau_i^{NC} := (1-\sum_{j<i}\theta_i\beta_i)\left(r-\frac{r-r_0}{\beta_i}\right)$. *The optimal non-cancelable contract obtains the first-best benchmark if and only if*

$$c^E \leq C_{i^{FB}}^U - \left[T-(\tau_{i^{FB}}^{NC}-C_{i^{FB}}^U)\right]^+. \tag{2}$$

The corresponding contract is:

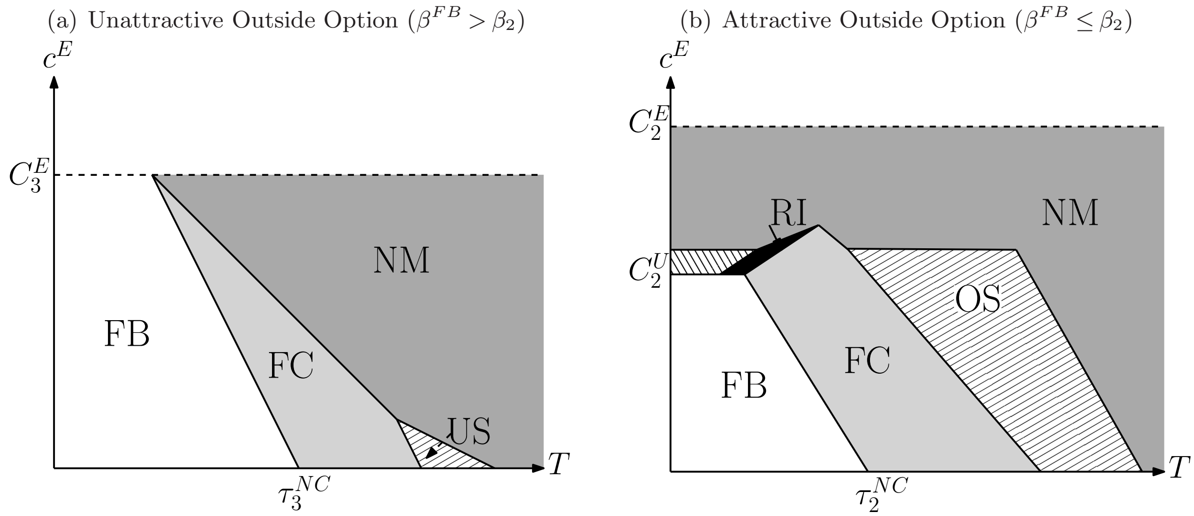
$$\delta^{NC}=\delta^{NC,*}:=\frac{r-r_0}{\beta_i}-\frac{l(T+c^E-\tau_i^{NC})^+}{1+l(1-\sum_{i<i^{FB}}\theta_i\beta_i)}, \qquad p^{NC}=c^E+\sum_{i<i^{FB}}\theta_i\beta_i(r-\delta^{NC,*}). \tag{3}$$

Two observations are notable. First, when the first-best benchmark can be achieved, the contract sets a deductible level such that the supplier adopts an efficient shipping policy, i.e., she ships if and only if $i < i^{FB}$, which is the lowest i under which it is efficient for the supplier to cancel shipping. Second, the optimal non-cancelable contract can achieve first best only when both c^E and T are low. The corresponding ranges of (c^E, T) are illustrated in Figure 2 (Region FB). When the contract fails to achieve the first-best, the figure also highlights the corresponding sources of inefficiency such as inefficient shipping decision, the supplier's financing cost, and/or information rent surrender to the insurer.[14] Figure 2(a) represents the case where the supplier's outside option is unattractive, i.e., $\beta^{FB} > \beta_2$, or equivalently, $r_0 < (1-\beta_2)r$. Symmetrically, Figure 2(b) represents the case where the supplier's outside option is attractive ($\beta^{FB} > \beta_2$).

As shown in Figure 2, the non-cancelable contracts fails to achieve first-best when the supplier is severely financially constrained (large T). To see why, we note that the smoothing role of TCI

[14] For expositional brevity, we leave the analytical result on the optimal contract when the first-best cannot be achieved in the Appendix (Proposition C.1).

Figure 2 **Illustration of different regions under optimal non-cancelable contract**



Notes. C_i^E is as defined in Lemma 1. According to Lemma 1, the region that the insurer should exert monitoring effort under the first-best benchmark is $c^E \le \bar{C}^E = C_3^E$ for $\beta^{FB} > \beta_2$ (Figure 2(a)), and $c^E \le \bar{C}^E = C_2^E$ for $\beta^{FB} \le \beta_2$ (Figure 2(b)). C_i^U and τ_i^{NC} are as defined in Proposition 1. Under the optimal non-cancelable contract, in Region FB the supplier receives the *first-best* payoff. In Region FC, the supplier makes efficient shipping decisions but incurs *financing costs*. In Region RI, the supplier makes efficient shipping decisions, but surrenders information *rent* to the *insurer*. In Region OS, the insurer exerts effort but the supplier *over-ships*. In Region NM, the insurer does *not monitor* the buyer's risk and the supplier always ships the order. The detailed contracts when the first-best cannot be achieved are summarized in Proposition C.1.

requires the deductible to be sufficiently low, as otherwise, the supplier incurs financing costs even under coverage. This constraint on the level of deductible becomes more stringent as T increases. However, to fulfill the monitoring role of TCI, which requires the supplier to ship efficiently upon receiving the updated information, the deductible cannot be too low. This is captured by the definition of β^{NC} in (1): As δ^{NC} decreases, β^{NC} in general increases. In other words, when faced with a low deductible, the supplier has the incentive to adopt a more aggressive shipping policy, which in turn undermines the value of the updated information. Hence, when T is sufficiently large, these two competing demands on the deductible prevent the optimal non-cancelable contract from adequately fulfilling the dual roles of TCI. In this case, the optimal contract either keeps the deductible high to maintain efficient shipping, yet incurring financing cost (Region FC), or lowers deductible to control financing cost, yet resulting in the supplier's over-shipping behavior (Region OS).[15] As the supplier becomes extremely financially constrained (T increases), it becomes too

[15] When $\beta^{FB} > \beta_2$, it is possible that the optimal non-cancelable contract induces under-shipping, i.e., the supplier only ships at $i = 1$ (Region US). However, this region only exists under extremely restrictive conditions, and we never

costly to implement either solution, and it is economical to give up the monitoring role of TCI altogether, resulting in the contract that does not induce the insurer's monitoring effort (Lemma 4) to be the optimal one (Region NM).

To see why the optimal contract fails to achieve the first-best when c^E is high, note that a sufficiently high deductible is also not necessarily compatible with the monitoring role of TCI. Recall that in Section 4, we have established that the fulfilment of TCI's monitoring role requires adequate incentives for the supplier to ship efficiently, and for the insurer to exert effort. While satisfying the former requires a high deductible, as shown above, meeting the latter requires the deductible to be reasonably low. To see this, note that according to Lemma 3, the insurer exerts monitoring effort only if (NC-IC2) is satisfied. In other words, if δ^{NC} is sufficiently high, the negative impact of the buyer's default on the insurer is minimal, and thus dulls the insurer's incentive to monitor. As c^E increases, a smaller δ^{NC} is required to satisfy (NC-IC2), thus exacerbating the tension between the insurer's incentive to monitor and the supplier's incentive to comply. In summary, with deductible as the only lever available, the monitoring value of TCI alone creates a conflict of interest between the supplier and the insurer. As such, the non-cancelable contract fails to unlock the full potential of TCI even when the supplier is not financially constrained at all ($T = 0$). When c^E is extremely high and the first-best cannot be achieved, as illustrated in Figure 2(b), one of three possible scenarios may arise. 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 (NC-IR) is not binding. In other words, the insurer extracts some information rent (Region RI). Alternatively, similar to the case with large T, the optimal contract may also adopt a lower deductible level that leads to over-shipping (Region OS). Finally, for extremely high c^E, the contract again abandons monitoring (Region NM).

At a high level, the inefficiency resulting from the use of non-cancelable contracts in TCI is related to the mismatch between the dynamic nature of the incentive conflict under TCI and the static nature of the contract. Specifically, the monitoring role of TCI depends on the sequential actions of the insurer and the supplier. However, the deductible is the single lever in the contract to mitigate both moral hazards, and moreover, it is specified *ex ante* (i.e., before the information update). As such, it is often inadequate for mitigating the conflicts of interest between the two parties.

observe it in numerical studies with more realistic parameters. We refer the readers to the proof in Proposition C.1 for an example of this case.

6. Inducing risk monitoring with cancelable contracts

With an understanding of the limitation of non-cancelable contracts in the TCI setting, in this section, we investigate how a cancelable contract can mitigate this problem by allowing the insurer to cancel coverage *after* entering into the contract. As we show later, by incorporating a dynamic component, cancelable contracts can be better at realizing the potential values of TCI. However, we will also show that this cancelation option, by granting more flexibility to the insurer, may lead to an additional incentive issue that could be potentially harmful to the performance of the contract.

As in Section 5, we present our analysis in an order consistent with backward induction. In addition, we note that 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 only analyze 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

We first characterize the supplier's shipping policy and then the insurer's cancelation policy under a given insurance contract (p^C, δ^C, f^C), where $f^C \in [0, p^C]$ is the refund 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 is $-p^C + r - \beta_i[\delta^C + L(r - \delta^C - p^C)]$ if she ships and r_0 if she does not ship. Hence, the supplier ships the order if and only if $\beta_i \leq \beta^{CN}$,[16] where

$$\beta^{CN} := \frac{r - r_0}{\delta^C + L(r - p^C - \delta^C)}. \tag{4}$$

Note that β^{CN} has a similar form to β^{NC} in (1), except that p^{NC} and δ^{NC} are replaced by p^C and δ^C, respectively.

In the case that the insurance is canceled, under the signal of group i, the supplier's payoff is $-p^C + r + f^C - \beta_i[r + L(f^C - p^C)]$ if she ships and $-p^C + r_0 + f^C$ if she does not. Comparing the two payoffs, the supplier ships if and only if $\beta_i \leq \beta^{CC}$, where

$$\beta^{CC} := \frac{r - r_0}{r + L(f^C - p^C)}. \tag{5}$$

As shown, because $L(\cdot) \geq 0$, we have $\beta^{CC} \leq \beta^{FB}$, suggesting that the cancelation of coverage can help prevent the supplier from over-shipping.

[16] The C in the double superscript is for *cancelable* contract, and the N denotes that the coverage is *not canceled*. A similar logic is applied for the double superscript CC introduced later, with *not canceled* replaced by *canceled*.

In anticipation of the supplier's shipping decision described above, the insurer decides whether to cancel coverage. Since the insurer must refund f^C to the supplier if he cancels, the insurer never cancels when $\beta_i > \beta^{CN}$, for which the supplier would never ship the order even if coverage were not canceled. However, if the supplier does ship the order when coverage is not canceled, the expected claims-related cost to the insurer is $\beta_i(r - \delta^C)$. Balancing the refund f^C and the expected claims cost, the insurer cancels coverage if and only if $\beta_i \in [\beta^C, \beta^{CN})$, where

$$\beta^C := \frac{f^C}{r - \delta^C}. \tag{6}$$

In other words, the insurer only cancels 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 β^{CN} can exceed 1 when δ^C is sufficiently small, at which point the insurer's cancelation policy degenerates to a simple threshold policy.

LEMMA 5. *Under any cancelable contract in which the insurer exerts effort and actually cancels coverage at certain signals,* $\beta^{CN} > \max(\beta^C, \beta^{CC})$. *Under such a contract,*

1. *the insurer cancels coverage if and only if* $\beta_i \in [\beta^C, \beta^{CN}]$*;*
2. *The supplier ships if and only if* $\beta_i < \max(\beta^{CC}, \beta^C)$.

The above result confirms that, intuitively, under any cancelable contract such that the insurer does indeed cancel coverage for certain signals ($\beta^C < 1$), the supplier's shipping policy is more conservative when her coverage is actually canceled. This suggests that the cancelation option can act as another lever for the insurer to nudge the supplier to adopt a more efficient shipping policy.

6.2. Inducing the insurer's monitoring effort

With the insurer's cancelation and the supplier's shipping decisions incorporated, Lemma 6 presents the characteristics of a cancelable contract that induces the insurer to exert monitoring effort.

LEMMA 6. *Under a cancelable contract* (p^C, δ^C, f^C), *the insurer exerts monitoring effort if and only if all of the following four conditions are satisfied:*

$$\beta^{CN} \geq \bar{\beta}; \tag{C-IC1}$$

$$\bar{\beta}(r - \delta^C) \geq c^E + \sum_{i<i^C} \theta_i \beta_i (r - \delta^C) + \sum_{i \in [i^C, i^{CN}]} \theta_i f^C; \tag{C-IC2}$$

$$f^C \geq c^E + \sum_{i<i^C} \theta_i \beta_i (r - \delta^C) + \sum_{i \in [i^C, i^{CN}]} \theta_i f^C; \tag{C-IC3}$$

$$p^C \geq c^E + \sum_{i<i^C} \theta_i \beta_i (r - \delta^C) + \sum_{i \in [i^C, i^{CN}]} \theta_i f^C; \tag{C-IR}$$

where $i^C = \min\{i : \beta_i > \beta^C\}$ *and* $i^{CN} = \max\{i : \beta_i \leq \beta^{CN}\}$.

By comparing the conditions that induce the insurer's monitoring effort under cancelable contracts with the ones under non-cancelable ones, we note that (C-IC1), (C-IC2), and (C-IR) are analogous to their counterparts in Lemma 3. However, three differences are notable. First, the insurer's expected cost when exerting effort, as in the right hand side of (C-IC2), (C-IC3), and (C-IR) includes not only the monitoring cost and the expected claim payment when the insurance is not cancelled and the supplier ships ($\sum_{i<i^C}\theta_i\beta_i(r-\delta^C)$), but also his expected refund $\sum_{i\in[i^C,i^{CN}]}\theta_i f^C$. Relatedly, the default risk thresholds correspond to the supplier's shipping policy and the insurer's cancelation policy under the cancelable contract. Specifically, i^C is the lowest signal that the insurer cancels coverage, i^{CN} is the highest signal that the supplier ships when coverage is not canceled. Symmetrically, we define $i^{CC}=\max\{i:\beta_i\le\beta^{CC}\}$ as the highest signal that the supplier ships when coverage is canceled. Finally, note that the cancelation option has imposed a new IC constraint, (C-IC3). It specifies that it is more cost-efficient for the insurer to exert effort than to always cancel coverage and offer a refund.

6.3. The power of cancelable insurance

Among the contracts (p^C,δ^C,f^C) that induce the insurer's monitoring effort, it is in the interest of the supplier to choose the one that maximizes her own payoff, that is,

$$\begin{aligned}\max_{p^C,\delta^C\in[0,r],f^C\le p^C}\ &\sum_{i<i^C}\theta_i[r-\beta_i(\delta^C+L(r-p^C-\delta^C))]+\sum_{i=i^C}^{i^{CC}}\theta_i[(1-\beta_i)r-\beta_iL(f^C-p^C)]\\ &+\sum_{i\ge\max(i^C,i^{CC}+1)}\theta_i r_0+\sum_{i=i^C}^{i^{CN}}\theta_i f^C-p^C.\end{aligned}\tag{C-OBJ}$$

subject to (C-IC1) –(C-IR). (C-OBJ) shows that under cancelable contracts, the supplier's expected payoff consists of five parts: her expected net revenue (revenue minus deductible and financing cost) when she ships under coverage ($i<i^C$), her expected net revenue when she ships without coverage ($i\in[i^C,i^{CC}]$), her outside option when she does not ship ($i\ge\max(i^C,i^{CC}+1)$), the refund when the coverage is canceled ($i\in[i^C,i^{CN}]$), and the insurance premium.

Proposition 2. *The cancelable contract can achieve first-best if and only if $\beta_{i^{FB}-1}\le\bar\beta$ and*

$$c^E\ge\min_{i\in[i^{FB},N]}\left[\left(\sum_{j<i^{FB}}\theta_j(\beta_{i^{FB}-1}-\beta_j)+\sum_{j>i}\theta_j\beta_{i^{FB}-1}\right)\max\left(r-\frac{r-r_0}{\beta_i},\ \frac{T}{1-\beta_{i^{FB}-1}}\right)\right].\tag{7}$$

Corollary 1. *The optimal cancelable contract can always achieve first-best when $\beta^{FB}\le\beta_2$. Under the following contract, the supplier achieves the first-best payoff:*

$$\delta^C=0;\qquad p^C=f^C=\frac{c^E}{\theta_1}+\beta_1 r.\tag{8}$$

Proposition 2 and Corollary 1 lay out the conditions under which the cancelable contract can fully recover the potential value of TCI. The most notable observation is that when the supplier's outside option is attractive ($\beta^{FB} \leq \beta_2$), the supplier can always achieve the first-best payoff under the optimal cancelable contract. This is in contrast with the performance of the optimal non-cancelable contract in the same region, as illustrated in Figure 2(b). The reason is as follows. When the supplier's outside option is attractive, as discussed in Section 5, the potential operational inefficiency is mainly the risk of over-shipping. However, recall from Lemma 5 that by canceling her coverage, the insurer can effectively nudge the supplier to adopt a more conservative, and hence efficient, shipping policy. In this sense, by allowing the insurer to cancel coverage at his discretion, a cancelable contract (partly) transfers control over the shipping decision from the supplier to the insurer. Furthermore, since he does not directly benefit from the upside potential of the trade, the insurer indeed tends to behave more conservatively. Consequently, granting more *ex post* discretionary power to the insurer deters over-shipping efficiently. Put differently, by allowing the insurer to cancel coverage, the cancelable contract partially decouples the two roles of TCI by effectively creating two levels of deductible: Under the risk level i for which shipping is efficient ($i < i^{FB}$), the supplier is covered by insurance. Under such circumstances, the smoothing role of TCI is fulfilled as the nominal deductible δ^C is kept low, as shown in Corollary 1. On the other hand, when shipping is inefficient ($i \geq i^{FB}$), the full monitoring value of TCI is realized via the cancelation of coverage, which effectively results in a deductible equal to r.

In contrast to the static nature of the non-cancelable contract, the merits of cancelable contract lies in its inherently dynamic nature. Specifically, the insurer's cancelation option is exercised after observing the updated information. Such an *ex post* action is contingent on the realization of the signal. This allows the supplier's moral hazard to be better mitigated, which in turn enhances the monitoring value of TCI. In addition, the cancelation option can only be exercised before the supplier's shipping decision, as cancelation afterwards does not corresponds 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.

6.4. The peril of cancelable contracts: over-cancelation

As shown in Proposition 2, although cancelable contracts are able to fully recover the potential value of TCI under some circumstances, they are imperfect. Specifically, such contracts cannot fully restore the first-best when the supplier's outside option is unattractive (large β^{FB}) and the monitoring cost is sufficiently low. The reason, interestingly, originates from the same source that grants cancelable contracts an advantage — the insurer's option to withdraw coverage. Intuitively, while such an option increases the flexibility of the contract, the flexibility is granted to the insurer (the agent in our model). Thus, it may not always benefit the supplier (the principal). 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 cancelation option according to his own best interest, which may not be fully aligned with the supplier's. Specifically, as previously shown, given signal i, under which the supplier will ship under coverage ($\beta_i < \beta^{CN}$), the insurer cancels coverage when his cost of doing so, i.e. the refund f^C, is less than his expected cost associated with the claim, $\beta_i(r-\delta^C)$. Therefore, for the insurer to *not* cancel at signal i, the contract terms must satisfy $\beta^C \geq \beta_i$, or equivalently,

$$f^C \geq \beta_i(r-\delta^C). \tag{9}$$

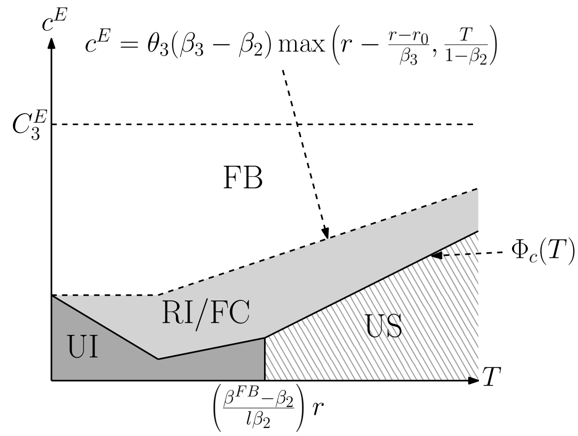
This condition alludes to the two possible scenarios where the insurer may prefer to over-cancel, i.e., cancel at β_i where $\beta_i < \beta^{FB}$. First, when the supplier's outside option is unattractive (large β^{FB}), it becomes more difficult to satisfy (9) for all i with $\beta_i < \beta^{FB}$. Second, when the insurer's monitoring cost is low, if (C-IR) is binding, the insurance premium p^C also tends to be low. As the refund f^C is capped by p^C in practice, (9) becomes more stringent as c^E decreases. Building on this line of reasoning, in Proposition 3 we characterize the optimal cancelable contracts when the first-best cannot be achieved.

Proposition 3. *When the optimal cancelable contract fails to achieve the first-best benchmark (i.e., either $\beta_2 \geq \bar{\beta}$, or $\beta_2 < \bar{\beta}$ and $c^E < \theta_1(\beta_2-\beta_1)\max\left(r-\frac{r-r_0}{\beta_3}, \frac{T}{1-\beta_M}\right)$), $\exists$ a threshold function $\Phi_C(\cdot) \geq 0$ such that the optimal cancelable contract and the insurer's and the supplier's corresponding actions are as summarized in the following table.*

Region name	*Range of* (T, c^E)	*Insurer cancels at*	*Supplier ships at*	*Financing cost*	*Information rent*
RI/FC	$c^E \geq \Phi_C(T)$	$i=3$	$i=1,2$	*Sometimes*	*Sometimes*
UI	$c^E < \Phi_C(T)$ *and* $T \leq \left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right) r$	$i=2,3$	$i=1,2$	*Yes*	*No*
US	$c^E < \Phi_C(T)$ *and* $T > \left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right) r$	$i=2,3$	$i=1$	*No*	*No*

Combining Proposition 3 with Proposition 2, Figure 3 illustrates the optimal cancelable contract when the supplier's outside option is not attractive. As shown, when c^E is sufficiently large (Region FB), the insurer demands a large premium to compensate for his monitoring cost. This allows for a large refund f^C, which provides sufficient incentive for the insurer to not cancel at all signals under which shipping is efficient. As such, the supplier can achieve the first-best payoff. As c^E decreases (Region RI/FC), to prevent the insurer from over-canceling, the supplier either pays the insurer a premium p^C that is higher than his expected cost so that the refund f^C is sufficiently high to

Figure 3 **Illustration of different regions under optimal cancelable contract.**



Notes. The illustration is generated under parameters $\beta^{FB} > \bar{\beta} > \beta_2$. In Region FB, the supplier achieves the first-best payoff. In Region RI/FC, the supplier ships efficiently (at $i = 1, 2$), but may incur *financing cost* and/or leaves *information rent* to the insurer. In Region UI, the shipping policy is efficient, but she is *under insured*, i.e., she is not covered by insurance when shipping at $i = 2$. In Region US, the supplier *under-ships* (only ships at $i = 1$). See Corollary C.1 for the specific expression of $\Phi_C(T)$ used in this Figure.

prevent over-cancelation, or incorporates a high deductible δ^{NC} which induces financing cost, in order to ensure that (9) is satisfied.

For even smaller c^E, it becomes too costly to incentivize the insurer to adopt an efficient cancelation policy. In response, the supplier chooses between two alternatives depending on her financial constraints. When she is less concerned about the financing cost (small T, Region UI), the supplier follows the efficient shipping policy, which means she ships at $i = 2$ uninsured. However, as T increases (Region US), the supplier adopts a conservative shipping policy and stops shipping at $i = 2$ (Region US). Such a dilemma is often faced by suppliers with canceled coverage. 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 the buyer's default risk was low, they canceled the order as they were unwilling to ship uninsured (Stacey 2009).

7. Mitigating over-cancelation

As shown above, while a cancelable contract can better fulfill the two roles of TCI, especially when the supplier faces attractive outside options or the insurer's cost of monitoring effort is high, it is not perfect. In particular, when the insurer's monitoring cost is low, the supplier may face the risk of over-cancelation, resulting in financial losses and possibly inefficient shipping decision. In this section, we discuss three mechanisms that could, to different degrees, mitigate this problem.

7.1. The advantage of non-cancelable contracts

The first mechanism that we examine is the non-cancelable contract, which we studied in Section 5. Intuitively, by stripping the cancelation option from the insurer, the risk of over-cancelation will be completely eliminated. In fact, as shown in the following Corollary, despite the intrinsic shortcomings of non-cancelable contracts, the optimal non-cancelable contract can be preferred over the optimal cancelable one for sufficiently small c^E.

COROLLARY 2. *When the supplier's outside option is unattractive ($\beta^{FB} > \beta_2$), there exists a threshold function $\Phi_{NC}(\cdot)$ such that for $c^E < \Phi_{NC}(T)$, the supplier's payoff under the optimal non-cancelable contract is strictly higher than that the optimal cancelable contract.*

A quick comparison between Figures 2(a) and Figure 3 illustrates the logic behind Corollary 2. When the supplier's outside option is attractive and both c^E and T are small, the optimal non-cancelable contract can recover the first-best payoff for the supplier, while the optimal cancelable one cannot. This result provides a plausible explanation for the recent emergence of non-cancelable contracts. Due to the adoption of superior information systems and other technological advances, the insurer's monitoring costs may be markedly lower than in the past. This could potentially drive down insurance premiums. However, as the above analysis suggests, a low premium generally leads to over-cancelation by the insurer, which is also consistent with the observation 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 favorable choice. Indeed, in the previously cited example, Total Security Systems may have been better off if they had entered into a non-cancelable contract.

The above analysis suggests that, at a high level, to fully recover the potential value of TCI, the optimal contract should strike the right balance between the flexibility offered by cancelable coverage and the commitment embodied in non-cancelable coverage. In the following sections, we examine two contract types that blend the advantage of non-cancelable contracts with cancelable ones by generalizing both classes of contracts, but do so in different ways.

7.2. Cancelable contracts with partially non-cancelable coverage

We note that in the cancelable contract that we studied in Section 6, once the insurance is canceled, the insurer is completely removed from any liability in case the buyer defaults. This feature partially explains the insurer's tendency to over-cancel. Targeting this shortcoming of cancelable contracts, we first examine the performance of *hybrid contracts*, in which part of the coverage is non-cancelable. Such hybrid contracts correspond to an emerging industry practice of adding non-cancelable coverage onto a cancelable contract. It is sometimes referred to as *top-up cover* on cancelable coverage (Insurance Journal 2012).

Hybrid contracts consist of four parameters: the insurance premium p^H, the amount refunded when the insurance is canceled f^H, where $f^H \leq p^H$, and the deductibles when the coverage is canceled (δ^{HC}) or not canceled (δ^{HN}), where $\delta^{HC} \geq \delta^{HN}$. As such, $r - \delta^{HC}$ is the portion of the coverage that is non-cancelable. In this sense, the cancelable contracts in Section 6 are a special case of hybrid contracts with $\delta^{HN} = \delta^C$ and $\delta^{HC} = r$, i.e. zero non-cancelable coverage. As cancelable contracts can fully recover the first-best when the supplier's outside option is attractive, this section focuses on when it is not, and under which neither the non-cancelable nor the cancelable contract can always recover the first-best payoff.

PROPOSITION 4. *When the supplier's outside option is unattractive ($\beta^{FB} > \beta_2$), the optimal hybrid contract achieves the first-best payoff* (Π^E) *for the supplier if and only if:*

$$c^E \geq \min\left(\frac{\theta_3(\beta_3 - \bar{\beta})}{1-\bar{\beta}}T,\ \frac{\theta_1(\beta_2 - \beta_1)}{1-\beta_2}\left[T - (r - \delta^{HC,*})\right] - \sum_{i=1}^{2}\theta_i\beta_i\left(r - \delta^{HC,*}\right)\right). \tag{10}$$

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

By comparing Proposition 4 with the results on pure cancelable or non-cancelable contracts discussed previously, we note that hybrid contracts greatly expand the parameter regions under which the first-best benchmark can be achieved. In particular, (10) holds for all (c^E, T) when the supplier's marginal financing cost l is sufficiently high or when the supplier's outside option is not extremely unattractive.

Hybrid contracts restore the first-best through two possible channels.[17] First, the non-cancelable coverage embedded in hybrid contracts may deter the insurer from over-canceling. Note that under hybrid contracts, the insurer is still liable for part of the supplier's loss even if he cancels coverage. Therefore, his cost of cancelation includes not only the refund f^H, but also the expected cost of the claim, $\beta_i(r - \delta^{HC})$, while the cost of not canceling remains $\beta_i(r - \delta^{HN})$. As a result, for the insurer to *not* cancel at signal i, the contract terms should satisfy:

$$f^H \geq \beta_i(\delta^{HC} - \delta^{HN}). \tag{11}$$

As $\delta^{HC} < r$, (11) is less stringent than (9), which specifies the insurer's incentive to cancel under cancelable contracts. Thus, it is easier for the contract to deter the insurer from over-cancelation.

The second channel through which hybrid contracts can restore the first-best is that even when the hybrid contract does not deter over-cancelation, as long as the non-cancelable coverage is sufficient for the supplier to avoid financing costs, the supplier is not harmed even if she ships when the insurer cancels.

[17] For expositional brevity, we leave the specifics of the optimal hybrid contract to Corollary C.2 in the Appendix.

7.3. Cancelable contracts with a cancelation penalty

The second type of contract that we consider is cancelable contracts with cancelation penalty. Specifically, the contract is the same as the cancelable contract in Section 6, except that when the insurer cancels the contract, he needs to pay a penalty f^{CP} to the supplier. We refer to f^{CP} as a penalty because it is not bounded above by the premium, as was the case for the *refund* in Section 6. Thus, the proposed contract generalizes the cancelable contract from Section 6. In addition, it also generalizes the non-cancelable contract, which can be seen as being associated with an infinitely large cancelation penalty.

PROPOSITION 5. *The cancelable insurance contract with cancelation penalty always achieves the first-best benchmark.*

Although such contracts have not been observed in practice – penalties are typically difficult to implement – Proposition 5 offers some encouraging theoretical support, calling for practitioners to innovate TCI contracts beyond the forms as they currently exist.

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. This paper fills that gap by examining a unique and puzzling feature in TCI – cancelability. We identify the monitoring role that the insurer plays in the TCI setting and highlight the supplier's and insurer's moral hazards associated with this role. We find that cancelable contracts are better at mitigating these incentive issues compared to non-cancelable contracts. We also uncover a drawback of cancelable contracts – the insurer's tendency to over-cancel when the supplier has unattractive outside options and the insurer's monitoring cost is low. In addition, we find that by combining the advantages of cancelable and non-cancelable coverage, hybrid contracts further enhance the value of TCI by merging (a level of) commitment with flexibility. These results echo the recent innovation of hybrid contracts in the TCI industry. Following the same principle of combining advantages, we further discover that a cancelable contract with cancelation penalty also mitigates the insurer's incentive to over-cancel.

By providing the economic rationale behind cancelability in TCI, this paper sheds light on how insurers can better design and deploy the most appropriate types of contract to customers. It also provides supply chain professionals with high-level guidance on how to select the most suitable trade credit insurance policy. The proper policy improves the shipping efficiency of existing business, and supports new customer acquisition by reducing the overall cost of doing business. As such, better use of TCI contracts can increase the volume of trade and benefit the economy as a whole.

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.

Finally, while the paper focuses on TCI, we believe that the principles we uncovered apply more generally. Specifically, cancelability can enhance the value of other types of insurance where the insurer is better equipped to monitor the insured risk. For example, an emergent insurance product, contingent business interruption (CBI) insurance, is also associated with insuring 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.[18] Thus, our results have the potential to inform risk management practice beyond TCI.

Acknowledgments

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

References

AIG. 2013. Special Report: Trade Credit Risks. *Strategic Risk* URL `http://www.aig.de/content/dam/aig/emea/germany/documents/brochure/specialreport-tradecredit.pdf`.

Aitken, P. 2013. Understanding Cancelable vs. Non-Cancelable Limits under Trade Credit Insurance Policies. URL `http://insurancenewsnet.com/oarticle/2013/10/30/Understanding-Cancelable-vs-Non-Cancelable-Limits-under-Trade-Credit-Insurance-a-412795.html`.

Babich, V. 2010. Independence of capacity ordering and financial subsidies to risky suppliers. *Manufacturing & Service Operations Management* **12**(4) 583–607.

[18] CBI insurance reimburses lost profits and extra expenses resulting from an interruption of business at the premises of a customer or supplier.

Babich, V., C. S Tang. 2012. Managing opportunistic supplier product adulteration: Deferred payments, inspection, and combined mechanisms. *Manufacturing & Service Operations Management* **14**(2) 301–314.

Bhattacharyya, S., F. Lafontaine. 1995. Double-sided moral hazard and the nature of share contracts. *The RAND Journal of Economics* 761–781.

Birchall, J. 2008. Circuit City prepares to pull the plug on 155 stores. *Financial Times* URL `http://www.ft.com/cms/s/0/44cf9800-aa10-11dd-958b-000077b07658.html#axzz3z7LqYBjg`.

Boissay, F., R. Gropp. 2013. Payment defaults and interfirm liquidity provision. *Review of Finance* **17** 1853–1894.

Bolton, P., M. Dewatripont. 2005. *Contract theory*. MIT press.

Chod, J. 2015. Inventory, risk shifting, and trade credit. *Management Science* Forthcoming.

Cooper, R., T. W Ross. 1985. Product warranties and double moral hazard. *The RAND Journal of Economics* 103–113.

Corbett, C. J, G. A DeCroix, A. Y Ha. 2005. Optimal shared-savings contracts in supply chains: Linear contracts and double moral hazard. *European Journal of Operational Research* **163**(3) 653–667.

Ding, Q., L. Dong, P. Kouvelis. 2007. On the integration of production and financial hedging decisions in global markets. *Operations Research* **55**(3) 470–489.

Dong, L., S. Y. Tang, B. Tomlin. 2015. Production chain disruptions: Inventory, preparedness, and insurance. Working Paper.

Dong, L., B. Tomlin. 2012. Managing disruption risk: The interplay between operations and insurance. *Management Science* **58**(10) 1898–1915.

Emons, W. 1988. Warranties, moral hazard, and the lemons problem. *Journal of Economic Theory* **46**(1) 16–33.

Freely, E. 2012. Risk Spolight: European Debt Crisis Rattles Trade Credit Insurance Market. URL `https://usa.marsh.com/Portals/9/Documents/RiskSpotlightJuly2012.pdf`.

Froot, K. A, D. S Scharfstein, J. C Stein. 1993. Risk management: Coordinating corporate investment and financing policies. *The Journal of Finance* **48**(5) 1629–1658.

Gaur, V., S. Seshadri. 2005. Hedging inventory risk through market instruments. *Manufacturing & Service Operations Management* **7**(2) 103–120.

Giannetti, M., M. Burkart, T. Ellingsen. 2011. What you sell is what you lend? explaining trade credit contracts. *Review of Financial Studies* **24**(4) 1261–1298.

Hennessy, C. A, T. M Whited. 2007. How costly is external financing? evidence from a structural estimation. *The Journal of Finance* **62**(4) 1705–1745.

Hölmstrom, B. 1979. Moral hazard and observability. *The Bell journal of economics* 74–91.

Iancu, D. A, N. Trichakis, G. Tsoukalas. 2015. Is operating flexibility harmful under debt? *Management Science* Forthcoming.

Insurance Journal. 2012. Coface Introduces New Trade Credit Top-Up Cover. URL `http://www.insurancejournal.com/news/national/2012/12/05/272840.htm`.

International Credit Insurance & Surety Association. 2015. *A guide to trade credit insurance*. Anthem Press.

International Credit Insurance and Surety Association. 2015. Trade Credit Insurance - Statistics. URL `http://www.icisa.org/statistics/1563/`.

International Financial Consulting. 2012. Study on short-term trade finance and credit insurance in the European Union. Prepared for the European Union, Contract number: COMP/2011/002.

Jain, N., S. Hasija, D. G Popescu. 2013. Optimal contracts for outsourcing of repair and restoration services. *Operations Research* **61**(6) 1295–1311.

Jones, P. M. 2010. Trade credit insurance. *Primer Series on Insurance* **15**.

Kaplan, S. N, L. Zingales. 1997. Do investment-cash flow sensitivities provide useful measures of financing constraints? *The Quarterly Journal of Economics* 169–215.

Kollewe, J. 2009. Budget credit insurance top-up scheme aims at helping firms survive recession. *The Guardian* URL `http://www.theguardian.com/uk/2009/apr/22/budget-top-up-credit-insurance`.

Kouvelis, P, L. Dong, O. Boyabatli, R. Li. 2011. *Handbook of integrated risk management in global supply chains*, vol. 1. John Wiley & Sons.

Kouvelis, P., R. Li, Q. Ding. 2013. Managing storable commodity risks: The role of inventory and financial hedge. *Manufacturing & Service Operations Management* **15**(3) 507–521.

Kouvelis, P., W. Zhao. 2011. The newsvendor problem and price-only contract when bankruptcy costs exist. *Production and Operations Management* **20**(6) 921–936.

Kouvelis, P., W. Zhao. 2012. Financing the newsvendor: supplier vs. bank, and the structure of optimal trade credit contracts. *Operations Research* **60**(3) 566–580.

Ma, A. C-T., M. H Riordan. 2002. Health insurance, moral hazard, and managed care. *Journal of Economics & Management Strategy* **11**(1) 81–107.

Milne, R. 2010. Late payments push smaller companies into bankruptcy. *Financial Times* URL `http://www.ft.com/cms/s/0/2bb66d42-37b0-11df-88c6-00144feabdc0.html#axzz3wvh0uR5u`.

Okuno-Fujiwara, M., A. Postlewaite, K. Suzumura. 1990. Strategic information revelation. *The Review of Economic Studies* **57**(1) 25–47.

Peura, H., S. A. Yang, G. Lai. 2016. Trade credit in competition: a horizontal benefit. *Manufacturing & Service Operations Management* Forthcoming.

Pulvino, T.C. 1998. Do asset fire sales exist? an empirical investigation of commercial aircraft transactions. *The Journal of Finance* **53**(3) 939–978.

Roels, Guillaume, Uday S Karmarkar, Scott Carr. 2010. Contracting for collaborative services. *Management Science* **56**(5) 849–863.

Rothschild, M., J. Stiglitz. 1976. Equilibrium in competitive insurance markets: An essay on the economics of imperfect information. *The Quarterly Journal of Economics* 629–649.

Serpa, J. C., H. Krishnan. 2015. The strategic role of business insurance. *Management Science* Forthcoming.

Shavell, S. 1979. On moral hazard and insurance. *The Quarterly Journal of Economics* 541–562.

Shavell, S. 1994. Acquisition and disclosure of information prior to sale. *The RAND Journal of Economics* 20–36.

Shleifer, A., R.W. Vishny. 2011. Fire sales in finance and macroeconomics. *Journal of Economic Perspectives* **25**(1) 29–48.

Stacey, K. 2009. Total Security Systems: What to do when oxygen supply is cut. *Financial Times* URL `http://www.ft.com/intl/cms/s/0/438b1210-2af5-11de-8415-00144feabdc0.html`.

Thomas, J. 2013. Companies turning to Trade Credit Insurance in an unpredictable and debt-laden world. White Paper, Zurich American Insurance Company.

Turcic, D., P. Kouvelis, E. Bolandifar. 2015. Hedging commodity procurement in a bilateral supply chain. *Manufacturing & Service Operations Management* **17**(2) 221–235.

van der Veer, K. J. M. 2015. The private export credit insurance effect on trade. *Journal of Risk and Insurance* **82**(3) 601–624.

Winter, R. A. 2013. Optimal insurance contracts under moral hazard. *Handbook of insurance*. Springer, 205–230.

Yang, S. A., J. R. Birge. 2009. How Inventory is (Should Be) Financed: Trade Credit in Supply Chains with Demand Uncertainty and Costs of Financial Distress. *SSRN eLibrary* doi:10.2139/ssrn.1734682.

Yang, S. A., J.R. Birge, R.P. Parker. 2015. The supply chain effects of bankruptcy. *Management Science* **61**(10) 2320–2338.

Zeckhauser, R. 1970. Medical insurance: A case study of the tradeoff between risk spreading and appropriate incentives. *Journal of Economic theory* **2**(1) 10–26.

Appendix A: List of Notation

Table 1 summarizes a list of notation. Superscript C, NC, H, and CP for contract parameters represents cancelable, non-cancelable, hybrid TCI contracts, and cancelable contracts with cancelation penalty, respectively.

Table 1 Notation

r	the credit price the supplier charges to the credit buyer.
r_0	the supplier's outside option, $r_0 < r$.
β^{FB}	$\beta^{FB} = \frac{r-r_0}{r}$.
T	the supplier's net cash flow threshold. She incurs financing cost when her net cash flow is below T.
l	the proportional financing cost incurred by the supplier.
c^E	insurer's cost of exerting monitoring effort.
β_i	the buyer's default probability when the signal is of type $i = 1, \ldots, N$. $0 < \beta_1 < \beta_2 \ldots < \beta_N < 1$.
θ_i	the probability that the insurer observes signal of group $i = 1, \ldots, N$, $\sum_{i=1}^N \theta_i = 1$.
$\bar{\beta}$	the prior expectation of the buyer's default probability, $\sum_{i=1}^N \theta_i \beta_i = \bar{\beta}$; $\bar{\beta} < \beta^{FB} < \beta_N$.
p^K	insurance premium $p^K \geq 0$; $K = C$, NC, H, CP.
δ^K	deductible, $\delta^K \in [0, r]$; $K = C$, NC, HC, HN, CP, $\delta^{HN} \leq \delta^{HC}$.
f^K	the refund the insurer pays to the supplier when the insurance is canceled, $f^K \in [0, p^K]$, $K = C$, H.
f^{CP}	the penalty the insurer pays to the supplier when the insurance is canceled under cancelable contracts with cancelation penalty.
Π^{NE}	$\Pi^{NE} = (1 - \bar{\beta})r$.
C_i^E	$C_i^E = r \sum_{j=i}^N \theta_i (\beta_i - \beta^{FB})$, $i = 1, \ldots, N$.
$\bar{C}^E$	$\bar{C}^E = \max_{i \geq 2} C_i^E$.
Π_i^E	$\Pi_i^E = \Pi^{NE} + C_i^E - c^E$, $i = 1, \ldots, N$.
Π^E	$\Pi^E = \Pi^{NE} + \bar{C}^E - c^E$.
i^K	$i^K = \min\{i : \beta_i > \beta^K\}$, $K = FB$, C.
i^K	$i^K = \max\{i : \beta_i \leq \beta^K\}$, $K = NC$, CC, CN.

Appendix B: Proofs

Proof of Lemma 1. To identify 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 $(1 - \bar{\beta})r \geq r_0$, or equivalently, $\bar{\beta} \leq \beta^{FB}$. As this condition always holds under Assumption 1, the supplier always ship and the corresponding payoff is $(1 - \bar{\beta})r := \Pi^{NE}$

2. When the insurer exerts effort and hence obtains updated information corresponding to default probability β_i, the supplier ships the order if and only if $\beta_i \leq \beta^{FB}$ for $i = 1, \ldots, N$. Let $i^{FB} = \min\{i : \beta_i > \beta^{FB}\}$ (also as defined in Proposition 1), the supplier's corresponding payoff is:

$$\Pi^E = \sum_{i < i^{FB}} \theta_i (1 - \beta_i) r + \sum_{i \geq i^{FB}} \theta_i r_0 - c^E = \Pi^{NE} + r \sum_{i \geq i^{FB}} \theta_i (\beta_i - \beta^{FB}) - c^E; \tag{12}$$

By comparing the above two scenarios, we can conclude that exerting effort is beneficial, i.e., $\Pi^E \geq \Pi^{NE}$, if and only if $c^E \leq r\sum_{i\geq i^{FB}}\theta_i(\beta_i - \beta^{FB})$. In addition, note that

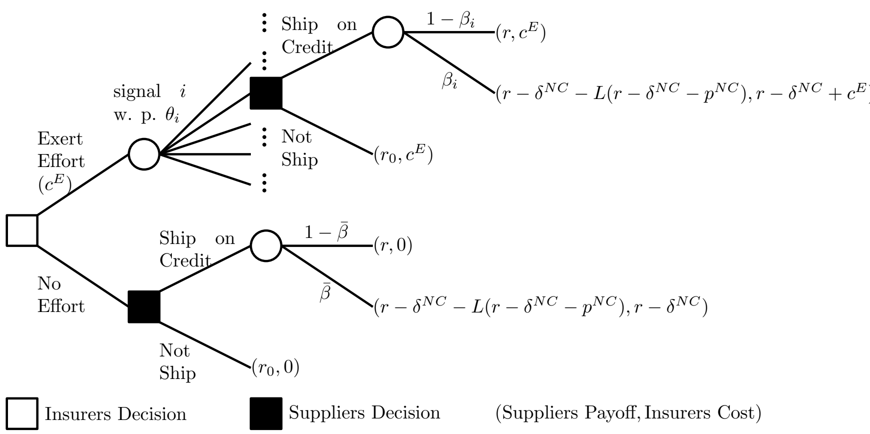
$$r\sum_{i\geq i^{FB}}\theta_i(\beta_i-\beta^{FB}) = r\sum_{i=1}^{N}\theta_i(\beta_i-\beta^{FB})^+ = \max_i r\sum_{j=i}^{N}\theta_j(\beta_j-\beta^{FB}) = \max_i C_i^E = \bar{C}^E. \tag{13}$$

Therefore, we have the following two scenarios regarding the optimal decision.

1. for $c^E \leq \bar{C}^E$, $\Pi^E \geq \Pi^{NE}$, and hence it is optimal for the insurer to exert effort, and the supplier ships if and only if $\beta_i \leq \beta^{FB}$.
2. for $c^E > \bar{C}^E$, $\Pi^E < \Pi^{NE}$. Correspondingly, the insurer does not exert effort, and the supplier always ships the order. □

Proof of Lemma 2. Without insurance, the supplier makes her shipping decision based on the prior expected default risk $\bar{\beta}$. If she ships, her expected payoff is $(1-\bar{\beta})r - \bar{\beta}(lT) =: \Pi^{NI}$. If she does not ship, her payoff is r_0. Therefore, she ships if and only if $\Pi^{NI} \geq r_0$, or equivalently, $\bar{\beta} \leq \frac{r-r_0}{r+lT}$. □

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



Proof of Lemma 3. 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.

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

1. For (NC-IC1), assume this condition is not satisfied under contract (p^{NC}, δ^{NC}), i.e., $\beta^{NC} < \bar{\beta}$. 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 upper branch in Figure 4). Suppose he does not exert effort. Then, the supplier's belief on the buyer's default risk remains to be the prior expectation, $\bar{\beta}$. As $\beta^{NC} < \bar{\beta}$, the supplier never ships, and hence the insurer's total cost is zero. On the other hand, the insurer's total costs is at least c^E when he exerts effort. By comparing these two costs, we can conclude that under $\beta^{NC} < \bar{\beta}$, the insurer does not have the incentive to exert effort.

2. Regarding (NC-IC2), when (NC-IC1) 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 $\bar{\beta}(r-\delta^{NC})$, the expected claim payout. On the other hand, his total cost with effort is the sum of the effort cost c^E and $(r-\delta^{NC})\sum_{i\le i^{NC}}\theta_i\beta_i$, the expected payout under the supplier's optimal shipping decision in response to updated information β_is, i.e., she ships if and only if $\beta_i \le \beta^{NC}$. By comparing the insurer's total costs between these two scenarios, we can see that the insurer only exerts effort when (NC-IC2) holds.
3. (NC-IR) 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 (NC-IC2). 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. □

Proof of Lemma 4. To show the stated results, note that under p^{NE} and δ^{NE}, the supplier always ships the order, and she always receives $r-\delta^{NE}=r$, whether the buyer defaults or not. Therefore, her payoff is $r-p^{NE}=\Pi^{NE}$, the same as the first-best payoff without insurer's effort, as in Lemma 1. Therefore, it cannot be dominated by any other contract that does not induce supplier's effort, under which the payoff of the supplier is no greater than Π^{NE}. □

Proof of Proposition 1. To identify when the optimal non-cancelable contract can achieve the first-best, we first note that according to C.2, among all non-cancelable contracts that could induce the insurer's effort, the optimal one must be either $(p^{NC}_{IC,i},\delta^{NC}_{IC,i})$ or $(p^{NC}_{IR,i},\delta^{NC}_{IR,i})$ for certain i. Consider these two classes of contracts separately.

First, for $(p^{NC}_{IC,i},\delta^{NC}_{IC,i})$, according to Lemma C.2, for any i, we also have $\Pi^{NC}_{IC,i}<\Pi^E_i\le\Pi^E$. Therefore, the first-best cannot be achieved under any $(p^{NC}_{IC,i},\delta^{NC}_{IC,i})$.

Next, consider $(p^{NC}_{IR,i},\delta^{NC}_{IR,i})$. According to Lemma C.2, we have that $\Pi^{NC}_{IR,i}=\Pi^E_i$ if and only if both of the following conditions hold:

$$c^E \le \tau_i^{NC} - T; \tag{14}$$

$$c^E \le C_i^U + \frac{l\sum_{j>i}\theta_j\beta_j}{1+(1-\bar{\beta})l}[T-(\tau_i^{NC}-C_i^U)]^+; \tag{15}$$

or equivalently,

$$c^E \le C_i^U - [T-(\tau_i^{NC}-C_i^U)]^+, \tag{16}$$

In addition, note that to achieve the first-best, the supplier ships if and only if $i<i^{FB}$, and hence the corresponding first-best payoff $\Pi^E=\Pi^E_{i^{FB}}$, which in turn equals to $\Pi^{NC}_{IR,i^{FB}}$ if and only if $c^E\le C^U_{i^{FB}}-[T-(\tau^{NC}_{i^{FB}}-C^U_{i^{FB}})]^+$. The corresponding optimal contract terms are $(p^{NC}_{IR,i^{FB}},\delta^{NC}_{IR,i^{FB}})$. □

Proof of Lemma 5. We prove the first part of the result, i.e., $\beta^{CN} > \max(\beta^C, \beta^{CC})$, by contradiction. First, suppose $\beta^{CN} \le \beta^{CC}$. By the definition of β^{CN} and β^{CC}, this condition is equivalent to:

$$r + L(f^C - p^C) \le \delta^C + L(r - p^C - \delta^C) \tag{17}$$

However, note that by the definition of deductible, we have $\delta^C \le r$, therefore, for (17) to hold, we must have $L(r - p^C - \delta^C) \ge L(f^C - p^C)$, or equivalently,

$$r - \delta^C \le f^C, \tag{18}$$

because $L(x)$ weakly decreases in x. By the definition of β^C in (6), (18) is equivalent to $\beta^C \ge 1$, 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 $\beta^{CN} > \beta^{CC}$.

Similarly, suppose that $\beta^{CN} \le \beta^C$. By the definition of β^{CN}, the supplier stops shipping even if her insurance coverage is *not* cancelled. In this case, the insurer does not have to cancel coverage even when $\beta_i > \beta^C$. In other words, the insurer will never cancel coverage, which also contradicts with the condition that the insurer cancels coverage at certain signals. Therefore, we must have $\beta^{CN} > \beta^C$.

Combining the above two scenarios, we have shown that $\beta^{CN} > \max(\beta^C, \beta^{CC})$. Given this result, we next prove the second part of the Lemma, i.e., the insurer's cancelation policy and the supplier's shipping policy. Specifically, consider when β_i falls into the following ranges,

1. for $\beta_i < \beta^C$, as $\beta^C < \beta^{CN}$, the insurer knows that if he does not cancel the coverage, the supplier will ship the order. Even though, his cost of canceling the contract, i.e., the refund f, is still greater than the expected payout, $\beta_i(r - \delta^C)$ because $\beta_i < \beta^C := \frac{f}{r-\delta^C}$. Therefore, in this region, the insurer does not cancel, and the supplier ships.

2. for $\beta_i \in [\beta^C, \max(\beta^{CC}, \beta^C))$, we further consider two cases,
   (a) if $\beta^{CC} < \beta^C$, $\max(\beta^{CC}, \beta^C) = \beta^C$, and hence $(\beta^C, \max(\beta^{CC}, \beta^C)] = \emptyset$, and the two parties' policies are thereby irrelevant.
   (b) if $\beta^{CC} \ge \beta^C$, the above region becomes $\beta_i \in (\beta^C, \beta^{CC})$. Similar to the Scenario 1, as $\beta^{CN} > \max(\beta^{CC}, \beta^C)$, the insurer knows that if he does not cancel, the supplier will ship the order. However, unlike the above scenario, in this region, the insurer's refund f is smaller than the expected payout, $\beta_i(r - \delta^C)$, 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, $(1 - \beta_i)r - L(f^C - p^C)$, because $\beta < \beta^{CC} := \frac{r-r_0}{r+L(f^C-p^C)}$. Therefore, the supplier still ships even when the insurer cancels her coverage.

3. for $\beta_i \in [\max(\beta^{CC}, \beta^C), \beta^{CN}]$, similar as Scenario 2(b), the insurer knows that if he does not cancel the coverage, the supplier will ship. As such, he will cancel the coverage as his cost of doing so, f^C, is less than the alternative $\beta_i(r - \delta^C)$. From the supplier's perspective, however, observing that her coverage is canceled, the supplier's payoff under not shipping, r_0, dominates that under shipping, $r - L(f^C - p^C)$, because $\beta^i \ge \beta^{CC}$. Therefore, she does not ship the order.

4. for $\beta_i > \beta^{CN}$, by the definition of β^{CN}, the insurer knows that even if he does not cancel the insurer's coverage, she will still not ship. As such, his cost under not canceling the coverage is zero, lowering than his cost by canceling the coverage, which is the refund f^C. 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.

Re-arranging the four regions, we arrive at the insurer's cancelation and the supplier's shipping policies as summarized in the lemma. □

Proof of Lemma 6. Similar to the proof of Lemma 3, we first show that (C-IC1) – (C-IR) are necessary for the insurer to exert effort.

First, note that (C-IC1) is analogous to (NC-IC1), 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 (C-IC2) – (C-IR) are identical, which equal to the total costs to the insurer if he exerts effort. The cost consists of three parts: the effort cost c^E, the insurer's expected payout when the insurer does not cancel *and* the supplier ships, $\sum_{i<i^C} \theta_i \beta_i (r - \delta^C)$, and the refund the insurer has to pay when he cancels the coverage, $\sum_{i \in [i^C, i^{CN}]} \theta_i f^C$. For the insurer to exert effort, his total cost of doing so must be (weakly) smaller than his other three options, corresponding the left hand side of (C-IC2) – (C-IR), respectively:

1. (C-IC2) 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 (C-IC1).
2. (C-IC3) 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^C.
3. (C-IR) states that 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^C.

For the sufficient side, similar to the proof in Lemma 3, 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. □

Proof of Proposition 2. First, we show that both $\beta_{i^{FB}-1} \le \bar{\beta}$ and (7) are necessary for a certain optimal cancelable contract to achieve the first-best. We do this by following three steps.

Step 1: We show that any contract that achieves the first-best payoff must satisfy that $i^C = i^{FB}$.

To see this, note that according to Lemma 5, the supplier ships if and only if $\beta_i < \max(\beta^{CC}, \beta^C)$, or equivalently, $i < \max(i^{CC}+1, i^C)$. Therefore, we should have $i^{FB} = \max(i^{CC}+1, i^C)$. Suppose that $i^{FB} = i^{CC}+1 > i^C$. Then when $i = i^{CC}$, the supplier still ships even though her coverage is canceled. Because $L(0) = lT > 0$ for any $T > 0$, the supplier incurs financing costs in case the buyer defaults. Such costs push the supplier's payoff to be strictly lower than the first-best. Therefore, to achieve the first-best payoff, we must have $i^{FB} = i^C \ge i^{CC}+1$

Step 2: We show that any contract that achieves the first-best payoff must satisfy $\bar{\beta} \geq \beta_{i^{FB}-1}$.

By the definition of i^C, $i^{FB} = i^C$ can be translated to $\beta^C \in [\beta_{i^{FB}-1}, \beta_{i^{FB}})$, or equivalently,

$$f^C \geq \beta_{i^{FB}-1}(r - \delta^C). \tag{19}$$

$$f^C < \beta_{i^{FB}}(r - \delta^C); \tag{20}$$

In addition, for the contract to achieve the first-best payoff, the insurer must not extract any rent, i.e., his IR constraint (C-IR) must be binding. Combining this condition with one of the insurer's IC constraint (C-IC3), and the constraint that the refund cannot exceed the premium ($p^C \geq f^C$), we have that the refund must satisfy:

$$f^C = c^E + \sum_{i<i^{FB}} \theta_i \beta_i (r - \delta^C) + \sum_{i \in [i^{FB}, i^{CN}]} \theta_i f^C. \tag{21}$$

where i^{CN} follows the definition in Lemma 6.

Substituting this into (19), (20) and (C-IC2), as well as the constraint that no financing cost is incurred when the supplier ships under coverage ($T \leq r - \delta^C - f^C$), leads to:

$$\frac{c^E + \sum_{i<i^{FB}} \theta_i \beta_i (r - \delta^C)}{\sum_{i \notin [i^{FB}, i^{CN}]} \theta_i} \geq \beta_{i^{FB}-1}(r - \delta^C); \tag{22}$$

$$\frac{c^E + \sum_{i<i^{FB}} \theta_i \beta_i (r - \delta^C)}{\sum_{i \notin [i^{FB}, i^{CN}]} \theta_i} < \beta_{i^{FB}}(r - \delta^C); \tag{23}$$

$$\sum_{i \geq i^{FB}} \theta_i \beta_i (r - \delta^C) - \sum_{i \in [i^{FB}, i^{CN}]} \theta_i \left(\frac{c^E + \sum_{i<i^{FB}} \theta_i \beta_i (r - \delta^C)}{\sum_{i \notin [i^{FB}, i^{CN}]} \theta_i} \right) \geq c^E; \tag{24}$$

$$r - \delta^C - \frac{c^E + \sum_{i<i^{FB}} \theta_i \beta_i (r - \delta^C)}{\sum_{i \notin [i^{FB}, i^{CN}]} \theta_i} \geq T. \tag{25}$$

This set of conditions can be further re-arranged into the following ones.

$$r - \delta^C \leq \frac{c^E}{\sum_{i \notin [i^{FB}, i^{CN}]} \theta_i \beta_{i^{FB}-1} - \sum_{i<i^{FB}} \theta_i \beta_i}; \tag{26}$$

$$r - \delta^C > \frac{c^E}{\sum_{i \notin [i^{FB}, i^{CN}]} \theta_i \beta_{i^{FB}} - \sum_{i<i^{FB}} \theta_i \beta_i}; \tag{27}$$

$$r - \delta^C \geq \frac{c^E}{\sum_{i \notin [i^{FB}, i^{CN}]} \theta_i \sum_{i \geq i^{FB}} \theta_i \beta_i - \sum_{i \in [i^{FB}, i^{CN}]} \theta_i \sum_{i<i^{FB}} \theta_i \beta_i}; \tag{28}$$

$$r - \delta^C \geq \frac{c^E + \sum_{i \notin [i^{FB}, i^{CN}]} \theta_i T}{\sum_{i \notin [i^{FB}, i^{CN}]} \theta_i - \sum_{i<i^{FB}} \theta_i \beta_i}. \tag{29}$$

Therefore, the contract with a given i^{CN} can achieve the first-best payoff only if (26) – (29) can be jointly satisfied. Note that only (26) sets a lower bound for δ^C, while all other three specify the upper bound for δ^C. Further note that (26) and (27) can always co-exist because $\beta_{i^{FB}-1} < \beta_{i^{FB}}$. Therefore, we need only to identify the conditions that satisfy (26), (28), and (29).

For (26) and (28) to be satisfied jointly, we need:

$$\sum_{i \notin [i^{FB}, i^{CN}]} \theta_i \sum_{i \geq i^{FB}} \theta_i \beta_i - \sum_{i \in [i^{FB}, i^{CN}]} \theta_i \sum_{i<i^{FB}} \theta_i \beta_i \geq \sum_{i \notin [i^{FB}, i^{CN}]} \theta_i \beta_{i^{FB}-1} - \sum_{i<i^{FB}} \theta_i \beta_i. \tag{30}$$

which can be simplified into:

$$\bar{\beta} \geq \beta_{i^{FB}-1}, \tag{31}$$

as desired.

Step 3: We show that (7) **is necessary for achieving the first-best payoff.**

To prove that (7) is necessary for achieving the first-best payoff, we first lay out all conditions that constrain the range of β^{CN} (or equivalently, i^{CN}) that we can choose . First, note that according to Lemma 6, the contract has to satisfy $\beta^{CN} \geq \bar{\beta}$. However, as $\beta^{CN} > \beta^{C}$, we must have $i^{CN} \geq i^{C} = i^{FB}$, therefore, $\beta^{CN} \geq \bar{\beta}$ is satisfied automatically.

Second, by the definition of i^{CN}, we must have:

$$\beta^{CN} \in [\beta_{i^{CN}},\, \beta_{i^{CN}+1}]. \tag{32}$$

With a slight abuse of notation, we define $\beta_{N+1} = +\infty$, representing the case that the supplier always ships under coverage, i.e., $i^{CN} = N$. By the definition of β^{CN}, and the fact that no financing cost is incurred when the first-best can be achieved, we can re-writing (32) as the following two constraints.

$$\delta^{C} \geq \frac{r - r_0}{\beta_{i^{CN}+1}}; \tag{33}$$

$$\delta^{C} \leq \frac{r - r_0}{\beta_{i^{CN}}}. \tag{34}$$

Therefore, the contract (in particular, the deductible δ^{C}) can achieve the first-best payoff only if there exists an integer $i^{CN} \in (i^{FB}, N]$ such that (26)–(29), (33) and (34) can be jointly satisfied. Specifically, for (26) and (29) to be jointly satisfied, we need:

$$c^{E} \geq \left(\sum_{i<i^{FB}} \theta_i(\beta_{i^{FB}-1} - \beta_i) + \sum_{i>i^{NC}} \theta_i \beta_{i^{FB}-1} \right) \frac{T}{1 - \beta_{i^{FB}-1}}. \tag{35}$$

In addition, for (26) and (34) to be satisfied jointly, we need to have:

$$c^{E} \geq \left(\sum_{i<i^{FB}} \theta_i(\beta_{i^{FB}-1} - \beta_i) + \sum_{i>i^{NC}} \theta_i \beta_{i^{FB}-1} \right) \left(r - \frac{r - r_0}{\beta_{i^{CN}}} \right). \tag{36}$$

Combining (35) and (36) for all possible $i^{CN} \in (i^{FB}, N]$ leads to (7), as desired.

Next, we move to the proof of the sufficient side of this proposition, i.e., when both (7) and $\bar{\beta} \geq \beta_{i^{FB}-1}$ are satisfied, there indeed exists a contract $(p^{C}, \delta^{C}, f^{C})$ that achieves the first-best payoff. We prove this statement by construction.

First, we define the following functions for $j \in [i^{FB},\, N]$,

$$\delta^{C,*}(j) = \left(r - \frac{c^{E}}{\sum_{i \notin [i^{FB}, j]} \theta_i \beta_{i^{FB}-1} - \sum_{i<i^{FB}} \theta_i \beta_i} \right)^{+}; \tag{37}$$

$$p^{C,*}(j) = f^{C,*}(j) = \frac{c^{E} + \sum_{i<i^{FB}} \theta_i \beta_i (r - \delta^{C,*}(j))}{\sum_{i \notin [i^{FB}, j]} \theta_i}. \tag{38}$$

We note that under such $(\delta^{C,*}(j), p^{C,*}(j), f^{C,*}(j))$, when $j = i^{CN}$, the insurer extracts no surplus. Or equivalently, (C-IR) is binding. Further, we can verify that under the condition of $\bar{\beta} \geq \beta_{i^{FB}-1}$ and (35), (26) – (29) are all satisfied under $(\delta^{C,*}(j), p^{C,*}(j), f^{C,*}(j))$.

Next, define integer $i^{CN,*}$ as follows:

$$i^{CN,*} = \arg\min_{i\in[i^{FB},N]} \left[\left(\sum_{j<i^{FB}} \theta_j(\beta_{i^{FB}-1} - \beta_j) + \sum_{j>i} \theta_j \beta_{i^{FB}-1} \right) \cdot \max\left(r - \frac{r-r_0}{\beta_i}, \frac{T}{1-\beta_{i^{FB}-1}} \right) \right]. \tag{39}$$

By (7), c^E must satisfy:

$$c^E \geq \left(\sum_{i<i^{FB}} \theta_j(\beta_{i^{FB}-1} - \beta_i) + \sum_{i>i^{CN,*}} \theta_i \beta_{i^{FB}-1} \right) \cdot \max\left(r - \frac{r-r_0}{\beta_{i^{CN,*}}}, \frac{T}{1-\beta_{i^{FB}-1}} \right). \tag{40}$$

Thus, based on the above observation, (26) – (29) are all satisfied. Next, we need to verify that under $(\delta^{C,*}(i^{CN,*}), p^{C,*}(i^{CN,*}), f^{C,*}(i^{CN,*}))$, $i^{CN} = i^{CN,*}$, or equivalently,

$$\delta^{C,*}(i^{CN,*}) \geq \frac{r-r_0}{\beta_{i^{CN,*}+1}}; \tag{41}$$

$$\delta^{C,*}(i^{CN,*}) \leq \frac{r-r_0}{\beta_{i^{CN,*}}}. \tag{42}$$

If these two conditions are satisfied, then $(\delta^{C,*}(i^{CN,*}), p^{C,*}(i^{CN,*}), f^{C,*}(i^{CN,*}))$ can achieve first-best. If not, then we will construct a new contract.

Note that according to (40), we have

$$c^E \geq \left(\sum_{i<i^{FB}} \theta_j(\beta_{i^{FB}-1} - \beta_i) + \sum_{i>i^{CN,*}} \theta_i \beta_{i^{FB}-1} \right) \left(r - \frac{r-r_0}{\beta_{i^{CN,*}}} \right). \tag{43}$$

Therefore,

$$\delta^{C,*}(i^{CN,*}) = \left(r - \frac{c^E}{\sum_{i\notin[i^{FB},i^{CN}]} \theta_i \beta_{i^{FB}-1} - \sum_{i<i^{FB}} \theta_i \beta_i} \right)^+ < \frac{r-r_0}{\beta_{i^{CN,*}}}, \tag{44}$$

satisfying (42). Regarding (41), consider two scenarios.

1. If $\delta^{C,*}(i^{CN,*}) \geq \frac{r-r_0}{\beta_{i^{CN,*}+1}}$, then $i^{CN} = i^{CN,*}$, and hence the contract $(\delta^{C,*}(i^{CN,*}), p^{C,*}(i^{CN,*}), f^{C,*}(i^{CN,*}))$ achieves the first-best payoff.

2. If $\delta^{C,*}(i^{CN,*}) < \frac{r-r_0}{\beta_{i^{CN,*}+1}}$, then we need to construct a new contract. Define $i^{CN,**}$ as:

$$i^{CN,**} = \min_{j\in(i^{CN,*},N]} \left\{ \delta^{C,*}(j) \geq \frac{r-r_0}{\beta_{j+1}} \right\}. \tag{45}$$

We first note that the existence of such a $i^{CN,**}$ is guaranteed as $\delta^{C,*}(j) \geq 0 = \frac{r-r_0}{\beta_{N+1}}$.

Second, we show that $i^{CN} = i^{CN,**}$, i.e., both of the following two constraints are satisfied.

$$\delta^{C,*}(i^{CN,**}) \geq \frac{r-r_0}{\beta_{i^{CN,**}+1}}; \tag{46}$$

$$\delta^{C,*}(i^{CN,**}) \leq \frac{r-r_0}{\beta_{i^{CN,**}}}. \tag{47}$$

Note that by the definition of $i^{CN,**}$, (46) is satisfied. Regarding (47), by contradiction, assume that $\delta^{C,*}(i^{CN,**}) > \frac{r-r_0}{\beta_{i^{CN,**}}}$. Observe that $\delta^{C,*}(j)$ decrease in j, therefore, we should have:

$$\delta^{C,*}(i^{CN,**}-1) > \delta^{C,*}(i^{CN,**}) > \frac{r-r_0}{\beta_{i^{CN,**}}}. \tag{48}$$

This inequality, however, violates either the definition of $i^{CN,**}$, or the condition $\delta^{C,*}(i^{CN,*}) < \frac{r-r_0}{\beta_{i^{CN,*}+1}}$. Therefore, (47) must be satisfied.

Finally, we show that $(\delta^{C,*}(i^{CN,**}), p^{C,*}(i^{CN,**}), f^{C,*}(i^{CN,**}))$ also satisfies (26) – (29). To see that, note that as $i^{CN,**} > i^{CN,*}$, hence, by (40),

$$c^E \geq \left(\sum_{i<i^{FB}} \theta_j(\beta_{i^{FB}-1} - \beta_i) + \sum_{i>i^{CN,*}} \theta_i \beta_{i^{FB}-1} \right) \cdot \left(\frac{T}{1-\beta_{i^{FB}-1}} \right) \tag{49}$$

$$> \left(\sum_{i<i^{FB}} \theta_j(\beta_{i^{FB}-1} - \beta_i) + \sum_{i>i^{CN,**}} \theta_i \beta_{i^{FB}-1} \right) \cdot \left(\frac{T}{1-\beta_{i^{FB}-1}} \right). \tag{50}$$

Therefore, analogous to the above argument for $i^{CN,*}$, we can verify that (26) – (29) are all satisfied under $i^{CN,**}$. Thus, $(\delta^{C,*}(i^{CN,**}), p^{C,*}(i^{CN,**}), f^{C,*}(i^{CN,**}))$ is a contract that achieves the first-best payoff. □

Proof of Corollary 1. For the first condition in Proposition 2, i.e., $\beta_{i^{FB}-1} \leq \bar{\beta}$, note when $\beta_2 \geq \beta^{FB}$, $i^{FB} = 2$, and hence $\beta_{i^{FB}-1} = \beta_1 < \bar{\beta}$.

For the second condition in Proposition 2, i.e., (7), note that as $\beta_{i^{FB}-1} = \beta_1$, by setting $i = N$, we have:

$$\left[\left(\sum_{j<i^{FB}} \theta_j(\beta_{i^{FB}-1} - \beta_j) + \sum_{j>i} \theta_j \beta_{i^{FB}-1} \right) \cdot \max\left(r - \frac{r-r_0}{\beta_i}, \frac{T}{1-\beta_{i^{FB}-1}} \right) \right] = 0 \tag{51}$$

Therefore, (7) is always satisfied.

Next, to show that the contract in the Corollary can achieves the first-best payoff, we follow three steps.

1. Following the definition of i^{CN} and i^C in Lemma 6, we can verify that the contract under (8) leads to $i^{CN} = N$, and $i^{CC} \leq i^C = 2 = i^{FB}$.
2. We can further verify that the contract under (8) satisfy (C-IC1)–(C-IR). Therefore, the insurer exerts effort under this contract.
3. Substituting (8), as well as $i^{CN} = N$, $i^{CC} \leq i^C = i^{FB} = 2$ into (C-OBJ), we can verify that the supplier's payoff equals to the first-best payoff $\Pi^E = \Pi_2^E$, as desired. □

Proof of Proposition 3. For $N = 3$ and $\beta^{FB} > \beta_2$, to identify the optimal contract, we first specify all possible scenarios in terms of the insurer's cancelation policy, or equivalently, the thresholds i^C and i^{CN}; for each scenario, we either identify the optimal cancelable contract under this specific i^C and i^{CN}, or show that any cancelable contract under that scenario will be (weakly) dominated by other contracts.

By enumerating all possible combinations of i^C and i^{CN}, we find it is sufficient to consider only the following two cases.

1. The insurer cancels at $i = 2, 3$. This corresponds to $i^C = 2$ and $i^{CN} = 3$. The optimal contract in this scenario is summarized in Lemma C.5. We refer to the solution in this scenario *Solution II.* In this contract, the insurer does not extract any information rent. However, the supplier faces the problem of over-cancelation, i.e., the insurer cancels more aggressively than the first-best benchmark. Further, depending on the supplier's financial constraint T, the optimal contract can be discussed in two cases.
   (a) when $T \leq \left(\frac{\beta^{FB} - \beta_2}{l\beta_2} \right) r$, 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 $T > \left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right) r$, the supplier ships at $i=1$. That is, she under-ships. In this case, the supplier sacrifices operational profit to avoid financing cost.

2. The insurer cancels only at $i=3$. This corresponds to $i^C=3$ and $i^{CN}=3$. The optimal contract in this scenario is summarized in Lemma C.6. We refer to the solution in this case *Solution III.* In summary, under this contract, the supplier ships at $i=1,2$, i.e., as long as the insurance is not canceled. Under this scenario, 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 information rent to the insurer (through a higher premium).

For contracts that induce other cancelation policies (e.g., the insurer only cancels at $i=2$), as shown in Lemma C.7, they are all (weakly) dominated by the optimal contracts in the above two cases (Lemmas C.5 and C.6).

Next, to identify whether the contract under Lemma C.5 (Solution II) or Lemma C.6 (Solution III) corresponds to the optimal contract, we show that there exists a threshold function $\Phi_C(T)$ such that Solution II dominates Solution III if and only if $c^E \le \Phi_C(T)$. To prove this result, we define the efficiency loss of a contract as the difference between the first-best payoff Π_3^E and the supplier's payoff under this contract, Π^{III} under Solution III and Π^{II} under Solution II. Let the efficiency loss be Δ^{III} and Δ^{II}, respectively.

Using Lemma C.5, we can see that for any T, Δ^{II} is constant in c^E. For Lemma C.6, in the following, we show that for any given T, Δ^{III} is continuous and decreasing in c^E. To prove this result, we focus on the case with $\beta_2 \le \bar{\beta}$, and the case with $\beta_2 > \bar{\beta}$ is similar.

When $\beta_2 \le \bar{\beta}$ (Solution III.L), by considering each region independently (see Figure 5 following Lemma C.6 for an illustration of the different regions we consider here), we can see that within each region, Δ^{III} is continuous and decreasing in c^E. In addition, we can show that the supplier's payoff Π^{III} is continuous on c^E at the boundaries between different regions. For example, on the boundary between Solution III.L.1 and Solution III.L.2, i.e., $c^E = \theta_1(\beta_2-\beta_1)\left(r - \frac{r-r_0}{\beta_3}\right)$, we note that in Solution III.L.1, $\Delta^{III}=0$, and according to Solution III.L.2, $\Delta^{III}=0$. Therefore, the payoffs under Solutions III.L.1 and III.L.2 are continuous on the boundary. The continuity of Δ^{III} on other boundaries can be proven similarly.

Combining the monotonicity of Δ^{II} and Δ^{III}, we can see that for any T, as c^E increases, Δ^{II} remains constant, and Δ^{III} decreases. Therefore, there exists a function $\Phi_C(T)$ such that Solution II is optimal if and only if $c^E \le \Phi_C(T)$.

Finally, for $c^E \le \Phi_C(T)$, according to Lemma C.5, the supplier ships at $i=1,2$ when $T \le \left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right) r$, corresponding to the *UI* region in the Proposition. When $T > \left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right) r$, the supplier only ships at $i=1$, corresponding to the *US* region in the Proposition. □

Proof of Corollary 2. The result follows directly by comparing the three optimal cancelable contracts specified in Proposition 3 and the non-cancelable contracts that can achieve first-best in Proposition 1. Because the optimal non-cancelable contract can always achieve first-best when both c^E and T are sufficiently small, and the optimal cancelable cannot achieve the first-best in the same region, the non-cancelable contract is strictly preferred. □

Proof of Proposition 4. We prove this result in backward induction: We first identify the supplier's shipping policy under a certain hybrid contract, depending on whether the insurer cancels coverage. Following that, we characterize the insurer's cancelation policy. Finally, by considering all possible scenarios of the supplier's shipping and the insurer's cancelation policies that could lead to the first-best payoff, we established the conditions when the first-best payoff can be achieved.

First, we consider the supplier's shipping policy. Under the hybrid contract, for the supplier, when coverage is canceled, if the supplier ships, her payoff is $r + f^H - \beta_i[\delta^{HC} + L(r - \delta^{HC} + f^H - p^H)]$, and if she does not ship, her payoff is $r_0 + f^H$. Therefore, when the coverage is canceled, she ships if and only if

$$\beta_i < \beta^{HC} := \frac{r - r_0}{\delta^{HC} + L(r - \delta^{HC} + f^H - p^H)}. \tag{52}$$

Similarly, if the insurance is not canceled, she ships if and only if

$$\beta_i < \beta^{HN} := \frac{r - r_0}{\delta^{HN} + L(r - \delta^{HN} - p^H)}. \tag{53}$$

On the insurer's side, when deciding whether to cancel coverage, the insurer needs to consider four scenarios. If he cancels *and* the supplier still ships, his cost is $f^H + \beta_i(r - \delta^{HC})$. If he does not cancel *and* the supplier ships, his cost is $\beta_i(r - \delta^{HN})$. By comparing these two scenarios, we can see that when the supplier ships regardless of the cancelation decision, the insurer cancels the insurance if and only if

$$f^H + \beta_i\left(r - \delta^{HC}\right) < \beta_i\left(r - \delta^{HN}\right). \tag{54}$$

For the latter two scenarios, if the insurer cancels *and* the supplier does not ship, his cost is f^H; if he does not cancel *and* the supplier does not ship, the cost is 0. Therefore, if the supplier does not ship regardless of cancelation, the insurer never cancels. Finally, if the supplier ships if and only if the insurer does not cancel, then the insurer cancels if and only if

$$f^H < \beta_i\left(r - \delta^{HN}\right). \tag{55}$$

Next, we consider the possible optimal solutions that may achieve the first-best. To do so, we first note that when $\beta^{FB} > \beta_2$ (i.e., $i^{FB} = 3$), the first-best payoff can only be achieved when the supplier ships if and only if the signal $i = 1, 2$. However, note that different from the proof in Proposition 2, which requires $i^C = i^{FB}$ (where i^C is defined in Lemma 6) to achieve first-best, under the hybrid contract, because part of the coverage is non-cancelable, the first-best may still be achieved even when $i^C < i^{FB}$. Therefore, to explore what contracts can achieve first-best we consider two scenarios based on the insurer's cancelation policy: $i^C = 3$ and $i^C < 3$ (or equivalently, $i^C = 2$, because if $i^C = 1$, the insurer cancels at all signal, violating the necessarily condition for him to exert effort).

Scenario I: The insurer only cancels at $i = 3$ ($i^C = 3$). Under this cancelation policy, we only need to focus on the case that the supplier ships at $i = 1, 2$, as other shipping policies are not efficient, thus resulting in a payoff lower than the first-best. In addition, note that we also only need to consider the contract under which the supplier ships at $i = 1, 2$ even if her coverage is cancelled. In other words, $\beta^{HC} \in (\beta_2, \beta_3]$. This is because if $\beta^{HC} \leq \beta_2$, we can show the corresponding optimization problem effectively degenerates to a pure cancelable one. Therefore, to focus on the hybrid contract that strictly dominates the pure cancelable ones, we focus on the case where $\beta^{HC} \in (\beta_2, \beta_3]$. Accordingly, the optimization problem can be formulated as follows.

$$\max_{p^H,\delta^{HN},\delta^{HC},f^H} \quad \sum_{i=1}^{2}\theta_i\left\{r-\beta_i[\delta^{HN}+L(r-\delta^{HN}-p^H)]\right\}+\theta_3 r_0-p^H+\theta_3 f^H; \tag{56}$$

$$\text{s.t.} \quad p^H \geq c^E+\sum_{i=1}^{2}\theta_i\beta_i(r-\delta^{HN})+\theta_3 f^H; \tag{57}$$

$$f^H+\bar{\beta}(r-\delta^{HC}) \geq c^E+\sum_{i=1}^{2}\theta_i\beta_i(r-\delta^{HN})+\theta_3 f^H; \tag{58}$$

$$\bar{\beta}(r-\delta^{HN}) \geq c^E+\sum_{i=1}^{2}\theta_i\beta_i(r-\delta^{HN})+\theta_3 f^H; \tag{59}$$

$$p^H \geq f^H; \tag{60}$$

$$f^H+\beta_2(r-\delta^{HC}) \geq \beta_2(r-\delta^{HN}); \tag{61}$$

$$f^H < \beta_3(r-\delta^{HN}); \tag{62}$$

$$\beta_2 < \frac{r-r_0}{\delta^{HC}+L(r-\delta^{HC}+f^H-p^H)}; \tag{63}$$

$$\beta_3 \geq \frac{r-r_0}{\delta^{HC}+L(r-\delta^{HC}+f^H-p^H)}; \tag{64}$$

$$\beta_3 \leq \frac{r-r_0}{\delta^{HN}+L(r-\delta^{HN}-p^H)}. \tag{65}$$

The first three constraints are the insurer's IR and IC constraints, which follow the same form as their counterparts under the cancelable contract. Note that the constraint $\beta^{CN} > \bar{\beta}$ is satisfied automatically as $i^{CN} = 3$. In addition, (60) ensures that the size of the refund cannot exceed the premium. (63) dictates that the supplier ship at $i = 1, 2$ even when her coverage is (partially) cancelled, and (64) and (65) ensures that the supplier ships at $i = 3$ if her coverage is not canceled, as otherwise the insurer has no incentive to cancel at $i = 3$. Finally, (61) and (62) ensure that the insurer does not cancel at $i = 2$, but cancels at $i = 3$. The asymmetry between the two conditions is because without coverage, the supplier ships at $i = 2$, but not $i = 3$. Thus, the insurer's total cost under cancelation is $f^H + \beta_2(r - \delta^{HC})$ at $i = 2$, but only f^H at $i = 3$. Note that δ^{HC} 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 supplier achieves the first-best payoff if and only if there exists a contract $(p^H, \delta^{HN}, \delta^{HC}, f^H)$ that satisfies (57) – (65) and the following two additional constraints. First, (57) is binding, i.e.,

$$p^H = c^E+\sum_{i=1}^{2}\theta_i\beta_i(r-\delta^{HN})+\theta_3 f^H. \tag{66}$$

Second, the supplier does not incur financing cost when the coverage is not canceled, i.e.,

$$r-\delta^{HN}-p^H \geq T. \tag{67}$$

When both (66) and (67) are satisfied, the supplier's objective function (56) become Π_3^E, the first-best benchmark. Therefore, the first-best payoff can be achieved if and only if there exists (p^H, f^H, δ^{HN}, δ^{HC}) that satisfy (58) – (65), (66), and (67).

Further, we note that we can simplify the set of constraints as follows: first, given (59), (62) is redundant; second, when (67) holds, (65) can be simplified to

$$\delta^{HN} \le \frac{r - r_0}{\beta_3}. \tag{68}$$

Third, we note that everything else being equal, lowering δ^{HC} loosens all the constraints except for (64). Therefore, we can set δ^{HC} so that (64) is binding, i.e.,

$$\delta^{HC} = \frac{r - r_0}{\beta_3} - \frac{l}{1+l}\left[T + c^E - \tau_L^{NC} - (1-\theta_3)f^H + \sum_{i=1}^{2}\theta_i\beta_i\left(\frac{r - r_0}{\beta_3} - \delta^{HN}\right)\right]^+, \tag{69}$$

which also guarantees that (63) is satisfied. Fourth, following (69), observe that $\delta^{HC} \le \frac{r-r_0}{\beta_3}$. Therefore, for the region of c^E that we are interested in, i.e., $c^E \le C_3^E := \theta_3(\beta_3 - \beta^{FB})$, we have that $\theta_3\beta_3(r - \delta^{HC}) \ge c^E$. Under this condition, when (61) holds, (58) becomes redundant. After applying these four simplifications, the set of inequalities (58) – (67) can be simplified to the following set.

$$\delta^{HC} = \frac{r - r_0}{\beta_3} - \frac{l}{1+l}\left[T + c^E - \tau_L^{NC} - (1-\theta_3)f^H + \sum_{i=1}^{2}\theta_i\beta_i\left(\frac{r - r_0}{\beta_3} - \delta^{HN}\right)\right]^+; \tag{70}$$

$$\delta^{HN} \le \frac{r - r_0}{\beta_3}; \tag{71}$$

$$f^H \ge \beta_2(\delta^{HC} - \delta^{HN}); \tag{72}$$

$$f^H \le \frac{\left(1 - \sum_{i=1}^{2}\theta_i\beta_i\right)(r - \delta^{HN}) - (T + c^E)}{\theta_3}; \tag{73}$$

$$f^H \le \frac{c^E + \sum_{i=1}^{2}\theta_i\beta_i(r - \delta^{HN})}{1 - \theta_3}; \tag{74}$$

$$f^H \le \beta_3(r - \delta^{HN}) - \frac{c^E}{\theta_3}. \tag{75}$$

Among these constraints, note that (73) – (75) all set an upper bound for f^H and have the following interpretation: (73) ensures that the supplier does not incur any financing cost when shipping under coverage ($i = 1, 2$); (74) says that refund cannot be greater than premium; and (75) 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 δ^{HN}.

Scenario I.A. For $\delta^{HN} \le \min\left(r - \frac{c^E + (1-\theta_3)T}{1 - \theta_3 - \sum_{i=1}^{2}\theta_i\beta_i},\, r - \frac{c^E}{\theta_3(\beta_3 - \bar{\beta})}\right)$, (73) is binding, and hence,

$$\delta^{HC} = \frac{r - r_0}{\beta_3} - \frac{l}{1+l}\left[T - \left(r - \frac{r - r_0}{\beta_3}\right)\right]^+. \tag{76}$$

As such, (70) – (75) can be simplified to:

$$\delta^{HN} \le r - \frac{c^E + (1-\theta_3)T}{1 - \theta_3 - \sum_{i=1}^{2}\theta_i\beta_i}; \tag{77}$$

$$\delta^{HN} \le r - \frac{c^E}{\theta_3(\beta_3 - \bar{\beta})}; \tag{78}$$

$$\delta^{HN} \le \frac{r - r_0}{\beta_3}; \tag{79}$$

$$\delta^{HN} \geq \frac{r-r_0}{\beta_3} - \frac{c^E + \sum_{i=1}^{2}\theta_i\beta_i\left(r-\frac{r-r_0}{\beta_3}\right) + \frac{(1-\theta_3)\beta_2 l}{1+l}\left[T-\left(r-\frac{r-r_0}{\beta_3}\right)\right]^+}{\theta_1(\beta_2-\beta_1)}. \tag{80}$$

Note that (80) ensures that if binding, $\delta^{HN} \leq \frac{r-r_0}{\beta_3}$, and hence we can drop (78). Furthermore, note that when $(\theta_1+\theta_2)\beta_2\beta^{FB} \leq \sum_{i=1}^{2}\theta_i\beta_i\beta_3$, or equivalently,

$$\beta^{FB} \leq \frac{\sum_{i=1}^{2}\theta_i\beta_i}{(\theta_1+\theta_2)\beta_2}\beta_3, \tag{81}$$

$\delta^{HN}=0$ satisfies all inequalities for any c^E and T.

On the other hand, if $(\theta_1+\theta_2)\beta_2\beta^{FB} > \sum_{i=1}^{2}\theta_i\beta_i\beta_3$, we consider two further scenarios depending on the range of c^E.

Scenario I.A.a. For $c^E \geq \frac{\theta_3(\beta_3-\bar{\beta})}{1-\bar{\beta}}T$, (78) is tighter than (77). Therefore, there exists a feasible δ^{HN} if and only if

$$\frac{(\bar{\beta}-\beta_2)c^E}{\theta_3(\beta_3-\bar{\beta})} + \beta_2\left(r-\frac{r-r_0}{\beta_3}\right) + \frac{\beta_2 l}{1+l}\left[T-\left(r-\frac{r-r_0}{\beta_3}\right)\right]^+ \geq 0, \tag{82}$$

which always holds for $c^E \leq C_3^E$.

Scenario I.A.b. For $c^E < \frac{\theta_3(\beta_3-\bar{\beta})}{1-\bar{\beta}}T$, (77) is tighter than (78), and hence there exists a feasible δ^{HN} for (77) – (80) if and only if:

$$c^E \geq \frac{\theta_1(\beta_2-\beta_1)T - (1-\theta_3-\sum_{i=1}^{2}\theta_i\beta_i)\beta_2\left(r-\frac{r-r_0}{\beta_3}+\frac{l\left[T-\left(r-\frac{r-r_0}{\beta_3}\right)\right]^+}{1+l}\right)}{1-\beta_2}, \tag{83}$$

which clearly holds for $T \leq r - \frac{r-r_0}{\beta_3}$. Combining (83) with $c^E \geq \frac{\theta_3(\beta_3-\bar{\beta})}{1-\bar{\beta}}T$ (in Scenario I.A.a) leads to the condition in the proposition.

Scenario I.B. For $\delta^{HN} > \min\left(r - \frac{c^E+(1-\theta_3)T}{1-\theta_3-\sum_{i=1}^{2}\theta_i\beta_i}, r - \frac{c^E}{\theta_3(\beta_3-\bar{\beta})}\right)$, either (74) or (75) is binding. With some algebra, we can show that the first-best payoff cannot be achieved outside the region as defined in (10). The details are omitted for expositional brevity.

Scenario II: The insurer cancels at $i=2,3$ ($i^C=2$). The other possible scenario for recovering first best is that the insurer cancels at $i=2$ yet the supplier still ships at $i=2$, but without incurring financing cost. This relaxes the constraint the insurer faces in terms of cancelation. However, it limits how large δ^{HC} can be. It also requires that the IR constraint be binding, i.e.

$$p^H = c^E + \sum_{i=2}^{3}\theta_i f^H + \theta_1\beta_1(r-\delta^{HN}) + \theta_2\beta_2(r-\delta^{HC}). \tag{84}$$

Under this scenario, the corresponding constraints are summarized as follows.

$$\theta_1 f^H \geq T - (1-\theta_2\beta_2)\left(r-\delta^{HC}\right) + c^E + \theta_1\beta_1(r-\delta^{HN}); \tag{85}$$

$$\theta_1 f^H \geq c^E + \theta_1\beta_1(r-\delta^{HN}) - (\theta_1\beta_1+\theta_3\beta_3)(r-\delta^{HC}); \tag{86}$$

$$\theta_1 f^H \leq c^E + \theta_1\beta_1(r-\delta^{HN}) + \theta_2\beta_2(r-\delta^{HC}); \tag{87}$$

$$f^H \leq \beta_2(\delta^{HC}-\delta^{HN}); \tag{88}$$

$$(1-\theta_1)f^H \leq \theta_3\beta_3(r-\delta^{HN}) + \theta_2\beta_2(\delta^{HC}-\theta^{HN}) - c^E; \tag{89}$$

$$(1-\theta_1)f^H \leq \left(1-\sum_{i=1}^{2}\theta_i\beta_i\right)(r-\delta^{HN})+\theta_2\beta_2(\delta^{HC}-\theta^{HN})-c^E-T; \tag{90}$$

$$\delta^{HC} \leq \frac{r-r_0}{\beta_2}; \tag{91}$$

$$\delta^{HC} \geq \frac{r-r_0}{\beta_3}; \tag{92}$$

$$\delta^{HN} \leq \frac{r-r_0}{\beta_3}. \tag{93}$$

(85) ensures that the supplier does not incur any financing cost when shipping uninsured $i=2$, (86) ensures that the insurer is better off to exert effort than to not exert effort and always cancel. (87) says that the refund cannot exceed the premium. (88) says that the insurer cancels at $i=2$, and (89) says that exerting effort is more cost-efficient for the insurer than not exerting effort and never canceling. (90) says that no financing cost incurs when insurance is not canceled.

With some algebra, we can verify that (85) – (93) only have a feasible solution if $T \leq r - \frac{r-r_0}{\beta_3}$, which is already covered in the region under Scenario I. Hence Scenario II does not enlarge the region where the first best can be achieved beyond (10). □

Proof of Proposition 5. In this proof, we show that there always exists a contract $(p^{CP}, \delta^{CP}, f^{CP})$ under which the first-best can be achieved. Without loss of generality, we focus on the case of $\delta^{CP}=0$, which guarantees that the supplier does not incur any financing cost under coverage regardless of T.

In addition, similar to the proofs of Propositions 2, we note that as there exists no non-cancelable coverage, to achieve the first-best, the contract must satisfy $i^C = i^{FB}$, or equivalently,

$$f^{CP} \geq \beta_{i^{FB}-1}r; \tag{94}$$

$$f^{CP} < \beta_{i^{FB}}r. \tag{95}$$

Also note that as shown in Section 6, $i^{CC} < i^{FB}$. Further, under $\delta^{CP}=0$, we can see that $\beta^{CN} > \beta_N$. Therefore, when $i^C = i^{FB}$, the supplier ships efficiently, i.e., she ships if and only if at i with $\beta_i < \beta^{FB}$.

Other conditions that are necessary to achieve first-best are:

1. the insurer has the incentive to exert effort, i.e.,

$$f^{CP} \geq c^E + \sum_{j<i^{FB}}\theta_j\beta_j r + \sum_{j\geq i^{FB}}\theta_j f^{CP}; \tag{96}$$

$$\bar{\beta}r \geq c^E + \sum_{j<i^{FB}}\theta_j\beta_j r + \sum_{j\geq i^{FB}}\theta_j f^{CP}. \tag{97}$$

   Note that $\beta^{CN} > \bar{\beta}$ is automatically satisfied as $\beta^{CN} > \beta_N$.

2. the insurer does not extract any rent, i.e.,

$$p^{CP} = c^E + \sum_{j<i^{FB}}\theta_j\beta_j r + \sum_{j\geq i^{FB}}\theta_j f^{CP} \tag{98}$$

When all of the above five constraints are satisfied, we can verified that the first-best can be achieved. Further, note that the premium p^{CP} only appears in the last equation. Therefore, to show that there exists a contract that achieves first-best, we only need to prove that the former four constraints lead to a feasible solution. We re-write these four inequalities as follows.

$$f^{CP} \geq \frac{c^E + \sum_{j<i^{FB}} \theta_j \beta_j r}{\sum_{j<i^{FB}} \theta_j}; \tag{99}$$

$$f^{CP} \geq \beta_{i^{FB}-1} r; \tag{100}$$

$$f^{CP} \leq \frac{\sum_{j\geq i^{FB}} \theta_j \beta_j r - c^E}{\sum_{j\geq i^{FB}} \theta_j}; \tag{101}$$

$$f^{CP} < \beta_{i^{FB}} r. \tag{102}$$

To identify a feasible solution, we consider the four constraints in the following four pairs.

1. (99) and (101) are jointly feasible if and only if

$$\frac{c^E + \sum_{j<i^{FB}} \theta_j \beta_j r}{\sum_{j<i^{FB}} \theta_j} \leq \frac{\sum_{j\geq i^{FB}} \theta_j \beta_j r - c^E}{\sum_{j\geq i^{FB}} \theta_j}, \tag{103}$$

or equivalently,

$$c^E \leq \left[\sum_{j\geq i^{FB}} \theta_j (\beta_j - \bar{\beta})\right] r, \tag{104}$$

which is always satisfied as $\bar{\beta} < \beta^{FB}$ and $c^E \leq C^E_{i^{FB}}$.

2. (100) and (101) are jointly feasible if and only if:

$$\beta_{i^{FB}-1} r \leq \frac{\sum_{j\geq i^{FB}} \theta_j \beta_j r - c^E}{\sum_{j\geq i^{FB}} \theta_j}, \tag{105}$$

or equivalently,

$$c^E \leq \left[\sum_{j\geq i^{FB}} \theta_j (\beta_j - \beta_{i^{FB}-1})\right] r, \tag{106}$$

which is always satisfied as $\beta_{i^{FB}-1} < \beta^{FB}$ and $c^E \leq C^E_{i^{FB}}$.

3. (99) and (102) are jointly feasible if and only if:

$$\frac{c^E + \sum_{j<i^{FB}} \theta_j \beta_j r}{\sum_{j<i^{FB}} \theta_j} < r\beta^{FB}_i, \tag{107}$$

or equivalently,

$$c^E \leq \sum_{j<i^{FB}} \theta_j (\beta_{i^{FB}} - \beta_j) r. \tag{108}$$

Note that $C^E_i = \sum_{j\geq i^{FB}} \theta_j (\beta_j - \beta^{FB})$, therefore,

$$\sum_{j<i^{FB}} \theta_j (\beta_{i^{FB}} - \beta_j) r - C^E_{i^{FB}} = \sum_{j<i} \theta_j (\beta_i - \beta_j) r - \sum_{j\geq i} \theta_j (\beta_j - \beta^{FB}); \tag{109}$$

$$= \left(\sum_{j<i^{FB}} \theta_j \beta_{i^{FB}} + \sum_{j\geq i^{FB}} \theta_j \beta^{FB} - \bar{\beta}\right) r > 0 \tag{110}$$

The last inequality holds as $\beta_{i^{FB}} > \beta^{FB} > \bar{\beta}$. Therefore, the first and fourth conditions are also jointly feasible for $c^E \leq C^E_{i^{FB}}$.

4. (100) and (102) can always hold jointly, as $\beta_i < \beta_{i+1}$ for any i.

Combining the above four pair comparisons, there always exists a f^{CP} such that all four constraints are satisfied, and the smallest one to achieve that is:

$$f^{CP} = \max\left(\frac{c^E + \sum_{j<i^{FB}} \theta_j \beta_j r}{\sum_{j<i^{FB}} \theta_j}, \ \beta_{i^{FB}-1} r\right). \tag{111}$$

Under this f^{CP}, $\delta^{CP} = 0$, and p^{CP} that satisfies (98), the first-best benchmark can always be achieved. □

Appendix C: Technical Lemmas (Proofs in Online Appendix D)

Lemma C.1 *The insurance premium under any TCI contract that is acceptable to the supplier is always lower than* $r - r_0$.

Lemma C.2 *Let* $C_i^U := \sum_{j \geq i} \theta_j \beta_j \left(r - \frac{r-r_0}{\beta_i}\right)$, *and* $\tau_i^{NC} := (1 - \sum_{j<i} \theta_i \beta_i)\left(r - \frac{r-r_0}{\beta_i}\right)$. *A non-cancelable contract under which the supplier ships if and only if at* $\beta_1, \ldots, \beta_{i-1}$, *for* $i \geq 2$, *exists if and only if* $\beta_i \geq \bar{\beta}$ *and* $c^E \leq r \sum_{j \geq i} \theta_j \beta_j$.

Under these two conditions, the optimal non-cancelable contract terms (p^{NC}, δ^{NC}) *and the supplier's corresponding payoff are:*

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

$$\delta^{NC} = \delta_{IR,i}^{NC} := \frac{r - r_0}{\beta_i} - \frac{l(T + c^E - \tau_i^{NC})^+}{1 + l(1 - \sum_{j<i} \theta_i \beta_i)}, \tag{112}$$

$$p^{NC} = p_{IR,i}^{NC} := c^E + \sum_{j \leq i-1} \theta_j \beta_j (r - \delta_{IR,i}^{NC}). \tag{113}$$

The supplier's corresponding payoff is:

$$\Pi_{IR,i}^{NC} := \Pi_i^E - \frac{\sum_{j<i} \theta_i \beta_i l(T + c^E - \tau_i^{NC})^+}{1 + l(1 - \sum_{j<i} \theta_j \beta_j)}. \tag{114}$$

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

$$\delta^{NC} = \delta_{IC,i}^{NC} := r - \frac{c^E}{\sum_{j \geq i} \theta_j \beta_j}, \tag{115}$$

$$p^{NC} = p_{IC,i}^{NC} := \frac{1}{l}\left(\frac{r - r_0}{\beta_i} - r\right) + \left(1 + \frac{1}{l}\right) \frac{c^E}{\sum_{j \geq i} \theta_j \beta_j} - T. \tag{116}$$

The supplier corresponding payoff is:

$$\Pi_{IC,i}^{NC} := \Pi_i^E - \left[\frac{(1 - \bar{\beta}) l c^E + (1 + \sum_{j<i} \theta_j \beta_j l)(c^E - C_i^U)}{l \sum_{j \geq i} \theta_j \beta_j} - T\right]. \tag{117}$$

Remark. Lemma C.2 characterizes the possible candidates for the optimal non-cancelable contracts. Fixing the supplier's shipping policy (by imposing a constraint), we observe the following properties for the optimal solution.

1. It is impossible to motivate the insurer to exert effort if the supplier does not ship even at average signal $\bar{\beta}$, or when c^E is greater than the value of the information.

2. We only need to focus on contracts that satisfy $\beta^{NC} = \beta_i$.

3. When the insurer's monitoring cost c^E is low, the binding constraint is the insurer's IR constraint. In addition, the first-best benchmark can be achieved when $T+c^E$ is small.
4. When c^E is high, the binding constraint is the insurer's IC constraint. In this region, the first-best benchmark cannot be achieved and the insurer extracts some information rent.

Lemma C.3 *For any $i \geq 2$, among non-cancelable contracts $(p^{NC}_{IR,i},\, \delta^{NC}_{IR,i})$, $(p^{NC}_{IC,i},\, \delta^{NC}_{IC,i})$, and $(p^{NE},\, \delta^{NE})$,*

1. *for $c^E \leq \min\left(C^U_i + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+(1-\bar{\beta})l}[T-(\tau^{NC}_i - C^U_i)]^+,\, C^E_i - \frac{l\sum_{j<i}\theta_j\beta_j}{1+l}[T-(\tau^{NC}_i - C^E_i)]^+\right)$, the optimal contract is $(p^{NC}_{IR,i}, \delta^{NC}_{IR,i})$;*
2. *for $c^E \in \left(C^U_i + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+(1-\bar{\beta})l}[T-(\tau^{NC}_i - C^U_i)]^+,\, C^U_i + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+l}[T-(\tau^{NC}_i - C^E_i)]\right]$, the optimal contract is $(p^{NC}_{IC,i}, \delta^{NC}_{IC,i})$;*
3. *otherwise, the optimal contract is (p^{NE}, δ^{NE}).*

Proposition C.1 *When $N=3$ and the optimal non-cancelable contract cannot achieve the first-best payoff ($c^E > C^U_{i^{FB}} - [T-(\tau^{NC}_{i^{FB}} - C^U_{i^{FB}})]^+$), the supplier's and the insurer's actions under the optimal non-cancelable contract are summarized in the following table.*

Panel A: *the supplier's outside option is unattractive ($\beta^{FB} > \beta_2$)*

Region name	*Range of (c^E, T)*	*Insurer exerts effort*	*Supplier ships at*	*Financing cost*	*Information rent*
FC	Ω^{FC}_h	*Yes*	$i=1,2$	*Yes*	*No*
US	Ω^{US}	*Yes*	$i=1$	*Yes*	*Sometimes*
NM	Ω^{NM}	*No*	$i=1,2,3$	*No*	*No*

Panel B: *the supplier's outside option is attractive ($\beta^{FB} \leq \beta_2$)*

Region name	*Range of (c^E, T)*	*Insurer exerts effort*	*Supplier ships at*	*Financing cost*	*Information rent*
FC	Ω^{FC}_l	*Yes*	$i=1$	*Yes*	*No*
RI	Ω^{RI}	*Yes*	$i=1$	*Yes*	*Yes*
OS	Ω^{OS}	*Yes*	$i=1,2$	*Sometimes*	*No*
NM	Ω^{NM}	*No*	$i=1,2,3$	*No*	*No*

Notes. Column 1 (region name) refers to the region in Figure 2. Column 2 characterizes the corresponding range of (c^E, T). For expositional brevity, the specific expressions of Ω^K_i are detailed in the proof of the proposition. Columns 3 and 4 give the insurer's and supplier's respective actions in the region, and columns 5 and 6 indicate the existence of two potential sources of inefficiency. Region US and OS only exist when β^{FB} and β_2 are sufficiently close. In Region US, the insurer receives information rent only when T is sufficiently small. In Region OS, the supplier incurs financing costs only when T is sufficiently large.

Lemma C.4 *Among all cancelable contracts that induce $i^C = j_1$, $i^{CC} = j_2$, and $i^{CN} = j_3$, the optimal cancelable contract is the solution to the following optimization problem.*

$$\max_{p^C, \delta^C \in [0,r], f^C \leq p^C} r_0 - p^C + \sum_{i<j_1} \theta_i[(r-r_0) - \beta_i(\delta^C + L(r - p^C - \delta^C))]$$

$$+\sum_{i=j_1}^{j_2}\theta_i[(r-r_0)-\beta_i(r+L(f^C-p^C))]+\sum_{i=j_1}^{j_3}\theta_i f^C. \tag{118}$$

$$\beta^{CN}\geq\bar{\beta} \tag{119}$$

$$\bar{\beta}(r-\delta^C)\geq c^E+\sum_{i<j_1}\theta_i\beta_i(r-\delta^C)+\sum_{i\in[j_1,j_3]}\theta_i f^C \tag{120}$$

$$f^C\geq c^E+\sum_{i<j_1}\theta_i\beta_i(r-\delta^C)+\sum_{i\in[j_1,j_3]}\theta_i f^C \tag{121}$$

$$p^C\geq c^E+\sum_{i<j_1}\theta_i\beta_i(r-\delta^C)+\sum_{i\in[j_1,j_3]}\theta_i f^C \tag{122}$$

$$f^C<\beta_{j_1}(r-\delta^C) \tag{123}$$

$$f^C\geq\beta_{j_1-1}(r-\delta^C) \tag{124}$$

$$\beta^{CN}\in(\beta_{j_3},\beta_{j_3+1}] \tag{125}$$

$$\beta^{CC}\in(\beta_{j_2},\beta_{j_2+1}] \tag{126}$$

Remark. Lemma C.4 gives the mathematical program that determines the optimal cancelable contract under which the insurer cancels at $i\in[j_1,\ j_3]$, and the supplier ships at $i\leq\max(j_1-1,\ j_2)$. By solving this math program that corresponds to all possible combinations j_1, j_2, and j_3, and comparing the corresponding optimal solutions, we can identify the optimal cancelable contracts.

Lemma C.5 (Solution II) *When $N=3$ and $\beta^{FB}>\beta_2$, a cancelable contract in which the insurer cancels coverage at $i=2,3$ (i.e., $i^C=2$ and $i^{CN}=3$) is feasible if and only if:*

$$c^E\leq\theta_1[\min(\bar{\beta},\beta_2)-\beta_1]r. \tag{127}$$

Within this region, the optimal contract is:

$$\delta^C=0;\qquad p^C=f^C=\frac{c^E}{\theta_1}+\beta_1 r. \tag{128}$$

In response,

1. *for $T\leq\left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right)r$, the supplier ships at $i=1,2$, and her payoff $\Pi^{II}=\Pi_3^E-l\theta_2\beta_2T$;*
2. *for $T>\left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right)r$, the supplier ships at $i=1$, and her payoff $\Pi^{II}=\Pi_2^E$.*

Remark. Lemma C.5 corresponds to the optimal contract under which the insurer cancels at $i=2,3$. When $\beta^{FB}>\beta_2$, this contract corresponds to over-cancelation. Under this contract, depending on T, the supplier's shipping policy follows two scenarios.

1. For small T, the supplier ships at $i=1,2$. That is, the shipping policy is efficient. However, the supplier incurs financing costs as she ships at $i=2$ uninsured.
2. For large T, the supplier ships at $i=1$. That is, the supplier under-ships. Compared with the first-best payoff Π_3^E, the supplier losses the operating profit $\theta_2[(1-\beta_2)r-r_0]$

Lemma C.6 (Solution III.) *Let $l_h=\frac{\theta_1(\beta_2-\beta_1)}{\sum_{i=1}^{2}\theta_i\beta_i(1-\beta_2)}$. When $N=3$ and $\beta^{FB}>\beta_2$, the optimal cancelable contract under which the insurer cancels only at $i=3$, and the supplier's corresponding payoff, is summarized as follows.*

For $\beta_2<\bar{\beta}$ **(Solution III.L)**,

1. *for* $c^E \geq \theta_1(\beta_2-\beta_1)\max\left(r-\frac{r-r_0}{\beta_3},\ \frac{T}{1-\beta_2}\right)$, $\delta^C = \left(r-\frac{c^E}{\theta_1(\beta_2-\beta_1)}\right)^+$, $p^C = f^C = \frac{c^E+\sum_{i=1}^2(r-\delta^C)}{\sum_{i=1}^2\theta_i}$, *and the supplier's payoff* $\Pi^{III} = \Pi_3^E$.
2. *for* $c^E < \theta_1(\beta_2-\beta_1)\left(r-\frac{r-r_0}{\beta_3}\right)$ *and* $T \leq (1-\beta_M)\left(r-\frac{r-r_0}{\beta_3}\right)$, $\delta^C = \frac{r-r_0}{\beta_3}$. $\Pi^{III} = \Pi_3^E - \left[\theta_1(\beta_2-\beta_1)\left(r-\frac{r-r_0}{\beta_3}\right)-c^E\right]$.
3. *for* $c^E < \frac{\theta_1(\beta_2-\beta_1)T}{1-\beta_2}$ *and* $T > (1-\beta_2)\left(r-\frac{r-r_0}{\beta_3}\right)$,
   (a) *if* $l \leq l_h$, $\delta^C = r-\frac{c^E}{\theta_1(\beta_2-\beta_1)}$, $\Pi^{III} = \Pi_3^E - \sum_{i=1}^2\theta_i\beta_i l\left(T-\frac{(1-\beta_2)c^E}{\theta_1(\beta_2-\beta_1)}\right)$.
   (b) *if* $l > l_h$, $\delta^C = r-\frac{T}{1-\beta_2}$, $\Pi^{III} = \Pi_3^E - \left(\frac{\theta_1(\beta_2-\beta_1)T}{1-\beta_2}-c^E\right)$.

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

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

Remark. Lemma C.6 characterizes the optimal contract under which the insurer cancels at $i=3$ and the supplier ships at $i=1,2$. For $\beta^{FB} > \beta_2$, both the cancelation and the shipping policies are efficient. However, when $\beta_2 \geq \bar{\beta}$, or c^E is sufficiently small, the supplier cannot achieve the first-best payoff. Instead, she faces financing cost (due to a high deductible) and/or leaves information rent to the insurer (the insurance premium is strictly greater than the insurer's cost.).

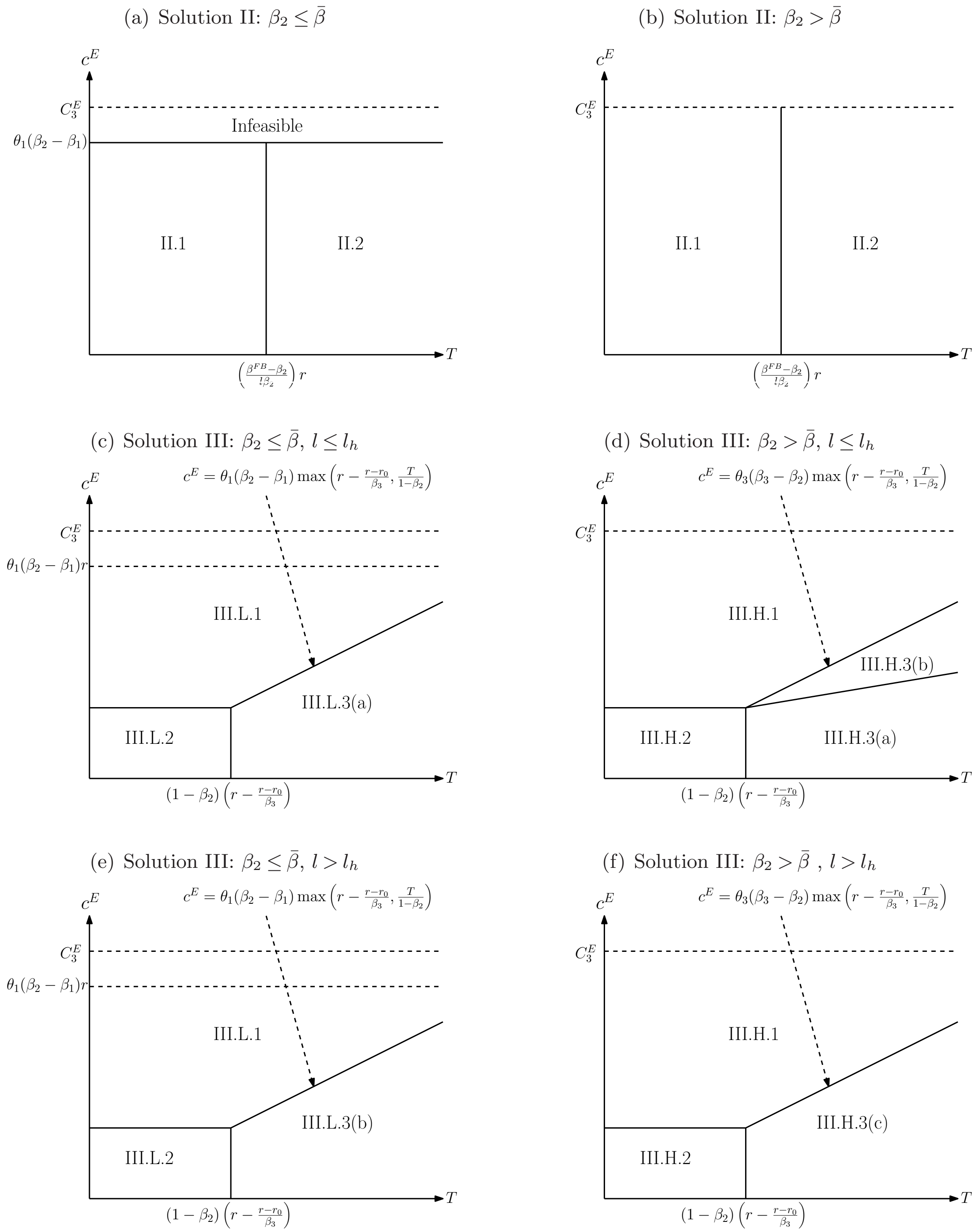
Lemma C.7 *When $N=3$ and $\beta^{FB} > \beta_2$, the supplier's payoff under any cancelable contract that induces the insurer to exert effort and cancel coverage at at least one group of signals is (weakly) dominated by either that under Solution II (Lemma C.5) or Solution III (Lemma C.6).*

Remark. Combining Lemmas C.5 – C.7, we note that to identify the optimal cancelable contracts for $N=3$ and $\beta^{FB} > \beta_2$, we only need to compare those contracts in Lemmas C.5 and C.6. Figure 5 illustrates the solution regions under different values in β_2, l, c^E, and T.

Corollary C.1 *When $N=3$ and $\beta^{FB} > \bar{\beta} > \beta_2$, if $l \leq \min\left(l_h, (1-\beta_2)\frac{1-\beta^{FB}/\beta_3}{\beta^{FB}/\beta_2-1}\right)$, the threshold function $\Phi_C(T)$ as defined in Proposition 3 is:*

$$\Phi_C(T) = \begin{cases} \theta_1(\beta_2-\beta_1)\left(r-\frac{r-r_0}{\beta_3}\right) - l\theta_2\beta_2 T & \text{for } T \leq (1-\beta_2)\left(r-\frac{r-r_0}{\beta_3}\right); \\ \theta_1\beta_1 l_h T & \text{for } T \in \left((1-\beta_2)\left(r-\frac{r-r_0}{\beta_3}\right), \left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right)r\right); \\ \frac{\theta_1(\beta_2-\beta_1)}{(1-\beta_2)}\left[T-\frac{\theta_2(\beta^{FB}-\beta_2)r}{\sum_{i=1}^2\theta_i\beta_i l}\right] & \text{for } T \geq \left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right)r. \end{cases} \tag{129}$$

Figure 5 Illustration of Results in Lemmas C.5 (Solution II) and C.6 (Solution III).



Remark. Corollary C.1 characterizes the specific expression of the threshold function $\Phi_C(T)$ that separates the regions of efficient cancelation (Solution III) and those of over cancelation (Solution II), as illustrated in Figure 3.

Corollary C.2 *When $N = 3$ and $\beta^{FB} > \beta_2$, two representative hybrid TCI contracts that achieve the first-best payoff for the supplier are summarized in following table, in which column 1 describes the applicable range, column 2 gives the level of non-cancelable coverage, and column 3 lists the insurer's cancelation action.*

Range of (T, c^E)	*Non-cancelable coverage* $(r - \delta^{HC})$	*Insurer cancels at*
$c^E \geq \frac{\theta_3(\beta_3 - \bar{\beta})}{1-\bar{\beta}} T$	$r - \delta^{HC,*}$	$i = 3$
$T \leq r - \frac{r-r_0}{\beta_3}$ *and* $c^E \leq \theta_1(\beta_2 - \beta_1) r - (\theta_1 + \theta_2)\beta_2 T$	T	$i = 2, 3$

Notes. $\delta^{HC,*} = \frac{r-r_0}{\beta_3} - \frac{l}{1+l}\left[T - \left(r - \frac{r-r_0}{\beta_3}\right)\right]^+$.

Online Appendix: Cancelability in Trade Credit Insurance

S. Alex Yang, Nitin Bakshi, Christopher J. Chen

Paper available on: `https://ssrn.com/abstract=2735907`

Appendix D: Proofs of Technical Lemmas

Proof of Lemma C.1. The supplier's payoff at the maximum is r minus the premium. If this payoff is less than her outside option r_0, she should never purchase the insurance.□

Proof of Lemma C.2. Following the analysis in Section 5, for the supplier to only ship at $j = 1, \ldots, i-1$, the contract must induce the insurer's monitoring effort. Therefore, the optimization problem that determines this optimal non-cancelable contract must have (NC-OBJ) as the objective, and (NC-IC1) – (NC-IR), as well as $\beta^{NC} \in (\beta_{i-1}, \beta_i]$ (which guarantees that $i^{NC} = i-1$) as constraints. For ease of reference, we re-write the optimization problem as follows.

$$\max_{p^{NC},\delta^{NC}\in[0,r]} \quad r_0 - p^{NC} + \sum_{j\le i-1} \theta_j \left\{(1-\beta_j)r + \beta_j[r - \delta^{NC} - L(r-\delta^{NC}-p^{NC})] - r_0\right\}; \tag{130}$$

$$\beta^{NC} \ge \bar{\beta}; \tag{131}$$

$$\delta^{NC} \le r - \frac{c^E}{\sum_{j\ge i}\theta_j\beta_j}; \tag{132}$$

$$p^{NC} \ge c^E + (r-\delta^{NC}) \sum_{j\le i-1} \theta_j\beta_j; \tag{133}$$

$$\beta^{NC} \in (\beta_{i-1}, \beta_i]. \tag{134}$$

By comparing (131) and (134), we note that the math program has no feasible solution when $\beta_i < \bar{\beta}$. In addition, we note that for $\delta^{NC} \ge 0$ to satisfy (132), we need $c^E \le r\sum_{j\ge i}\theta_j\beta_j$.

Under the condition $\beta_i \ge \bar{\beta}$, note that, according to (1), β^{NC} decreases in both δ^{NC} and p^{NC}. Thus, (131) and $\beta^{NC} > \beta_{i-1}$, i.e., the left half in (134), are both relaxed as δ^{NC} or p^{NC} decreases. Further, note that as $L(x)$ is weakly decreasing in x, the objective decreases in both δ^{NC} and p^{NC}. Thus, the optimal contract terms should push δ^{NC} and p^{NC} to be as low as possible, which relaxes (131) and $\beta^{NC} > \beta_{i-1}$. Therefore, these two constraints will not be the binding constraint for the optimization problem. In other words, the optimal solution is determined by (130), (132) – (133) and $\beta^{NC} \le \beta_i$, the last of which can be re-written as:

$$\delta^{NC} + L(r-\delta^{NC}-p^{NC}) \ge \frac{r-r_0}{\beta_i}. \tag{135}$$

Jointly considering (132), (133), and (135), we note that (132) does not involve p^{NC}. Therefore, at the optimal solution (p^{NC}, δ^{NC}), at least one of (133) and (135) must be binding, otherwise, $(p^{NC}-\epsilon, \delta^{NC})$ increases the objective while not violating any constraints.

Next, we show that any (p^{NC}, δ^{NC}) under which (135) is not binding must be (weakly) dominated by another solution. To see that, let (p^{NC}, δ^{NC}) be jointly determined by (132) and (133), that is,

$$\delta^{NC} = r - \frac{c^E}{\sum_{j\ge i}\theta_j\beta_j}; \tag{136}$$

$$p^{NC} = c^E + (r - \delta^{NC}) \sum_{j \le i-1} \theta_j \beta_j. \tag{137}$$

If (135) is not binding, consider the optimal $(p^{NC,1}, \delta^{NC,1})$ where

$$\delta^{NC,1} = \delta^{NC} - \epsilon; \tag{138}$$

$$p^{NC,1} = p^{NC} + \epsilon \sum_{j \le i-1} \theta_j \beta_j, \tag{139}$$

where $\epsilon > 0$. Substituting $(p^{NC,1}, \delta^{NC,1})$ into (132), (133), and (135), we note that for sufficiently small ϵ, all three constraints are satisfied, and hence $(p^{NC,1}, \delta^{NC,1})$ is a feasible solution. In addition, substituting $(p^{NC,1}, \delta^{NC,1})$ into the objective function, we have:

$$\pi(p^{NC,1}, \delta^{NC,1}) = r_0 - p^{NC,1} + \sum_{j \le i-1} \theta_j \left\{ (1-\beta_j) r + \beta_j [r - \delta^{NC,1} - L(r - \delta^{NC,1} - p^{NC,1})] - r_0 \right\}, \tag{140}$$

$$= r_0 - p^{NC} + \sum_{j \le i-1} \theta_j \left\{ (1-\beta_j) r + \beta_j [r - \delta^{NC} - L(r - \delta^{NC} - p^{NC} + \epsilon \sum_{j \ge i} \theta_i \beta_i)] - r_0 \right\}. \tag{141}$$

Consider two scenarios,

1. if $L(r - \delta^{NC} - p^{NC}) > 0$, then $\pi(p^{NC,1}, \delta^{NC,1}) > \pi(p^{NC}, \delta^{NC})$ as $L(x)$ decreases in x. Therefore, $(p^{NC,1}, \delta^{NC,1})$ strictly dominates $\pi(p^{NC}, \delta^{NC})$.
2. if $L(r - \delta^{NC} - p^{NC}) = 0$, then let $\epsilon = \frac{r - r_0}{\beta_i} - \delta^{NC}$. By construction, (135) is binding at $(p^{NC,1}, \delta^{NC,1})$, which also satisfy (132) and (133). Further, $\pi(p^{NC,1}, \delta^{NC,1}) = \pi(p^{NC}, \delta^{NC})$.

Combining the above two scenarios, we can see that any solution (p^{NC}, δ^{NC}) that is not binding at (135) is (weakly) dominated. Therefore, it is sufficient for us to consider (p^{NC}, δ^{NC}) such that (135) is binding.

Given that (135) is binding, we analyze the optimal solution depending on whether the other binding constraint is (132) or (133). Consider the following two scenarios.

1. If both (132) and (135) are binding, the optimal solution is determined by:

$$\delta^{NC} = \frac{r - r_0}{\beta_i} - L(r - \delta^{NC} - p^{NC}); \tag{142}$$

$$\delta^{NC} = r - \frac{c^E}{\sum_{j \ge i} \theta_j \beta_j} =: \delta^{NC}_{IC,i}. \tag{143}$$

As $L(\cdot) \ge 0$, the two equations lead to a feasible solution only if

$$c^E \ge \sum_{j \ge i} \theta_j \beta_j \left(r - \frac{r - r_0}{\beta_i} \right) =: C_i^U. \tag{144}$$

Under this condition, a feasible p^{NC} exists if and only if it satisfies the following two equations.

$$L\left(\frac{c^E}{\sum_{j \ge i} \theta_i \beta_i} - p^{NC} \right) = \frac{c^E - C_i^U}{\sum_{j \ge i} \theta_j \beta_j}. \tag{145}$$

$$p^{NC} \ge \frac{\bar{\beta} c^E}{\sum_{j \ge i} \theta_j \beta_j}. \tag{146}$$

Further consider two scenarios,

(a) if $c^E = C_i^U$, then p^{NC} exists if and only if

$$T - \frac{(1-\bar{\beta})c^E}{\sum_{j\geq i}\theta_j\beta_j} \leq 0, \tag{147}$$

or equivalently,

$$c^E \geq \frac{\sum_{j\geq i}\theta_j\beta_j}{1-\bar{\beta}}T. \tag{148}$$

(b) if $c^E > C_i^U$, then according to (145), p^{NC} follows:

$$l(T - r + \delta^{NC} + p^{NC}) = \frac{c^E - C_i^U}{\sum_{j\geq i}\theta_j\beta_j}, \tag{149}$$

or equivalently,

$$p^{NC} = \left(1+\frac{1}{l}\right)\frac{c^E}{\sum_{j\geq i}\theta_j\beta_j} - \frac{1}{l}\left(r - \frac{r-r_0}{\beta_i}\right) - T =: p_{IC,i}^{NC}, \tag{150}$$

which satisfies (146) if and only if:

$$\left(1+\frac{1}{l}\right)\frac{c^E}{\sum_{j\geq i}\theta_j\beta_j} - \frac{1}{l}\left(r - \frac{r-r_0}{\beta_i}\right) - T \geq \frac{\bar{\beta}c^E}{\sum_{j\geq i}\theta_j\beta_j}. \tag{151}$$

or equivalently,

$$c^E \geq \frac{C_i^U + lT\sum_{j\geq i}\theta_j\beta_j}{1+l(1-\bar{\beta})} =: \Phi_i^U(T). \tag{152}$$

which covers the region as defined in (148).

Combining the above two scenarios, we have that when $c^E \geq \max(C_i^U, \Phi_i^U(T))$, the optimal contract terms is $(p_{IC,i}^{NC},\, \delta_{IC,i}^{NC})$. Correspondingly, the supplier's payoff is:

$$\begin{aligned}\Pi^{NC} &= r_0 - p_{IC,i}^{NC} + \sum_{j\leq i-1}\theta_j\left\{(1-\beta_j)r + \beta_j[r - \delta_{IC,i}^{NC} - L(r - \delta_{IC,i}^{NC} - p_{IC,i}^{NC})] - r_0\right\} &(153)\\ &= \Pi_i^E - \left[\frac{(1-\bar{\beta})lc^E + (1+l\sum_{j<i}\theta_j\beta_j)(c^E - C_i^U)}{l\sum_{j\geq i}\theta_j\beta_j} - T\right] =: \Pi_{IC,i}^{NC} &(154)\end{aligned}$$

2. If both (133) and (135) are binding, according to (133),

$$p^{NC} = c^E + \sum_{j\leq i-1}\theta_j\beta_j(r - \delta^{NC}). \tag{155}$$

Substituting this into (135) leads to:

$$\delta^{NC} + L\left(\left[1 - \sum_{j\leq i-1}\theta_j\beta_j\right](r - \delta^{NC}) - c^E\right) = \frac{r-r_0}{\beta_i}, \tag{156}$$

To determine whether δ^{NC} as determined by the above equation can also satisfy (132), we further consider two scenarios.

(a) If δ^{NC} leads to $L\left(\left[1 - \sum_{j\leq i-1}\theta_j\beta_j\right](r - \delta^{NC}) - c^E\right) = 0$, it must follows:

$$\delta^{NC} = \frac{r-r_0}{\beta_i}. \tag{157}$$

This δ^{NC} satisfies both (132) and $L\left(\left[1-\sum_{j\le i-1}\theta_j\beta_j\right](r-\delta^{NC})-c^E\right)=0$ if and only if both of the following conditions are satisfied:

$$\frac{r-r_0}{\beta_i}\le r-\frac{c^E}{\sum_{j\ge i}\theta_j\beta_j}; \tag{158}$$

$$\left(1-\sum_{j\le i-1}\theta_j\beta_j\right)\left(\frac{r-r_0}{\beta_i}\right)-c^E\ge T. \tag{159}$$

or equivalently,

$$c^E\le\min\left(C_i^U,\,\tau_i^{NC}-T\right). \tag{160}$$

(b) If δ^{NC} results in $L\left(\left[1-\sum_{j\le i-1}\theta_j\beta_j\right](r-\delta^{NC})-c^E\right)>0$, using the functional form of $L()$, δ^{NC} follows:

$$\delta^{NC}+l\left(T-\left[1-\sum_{j\le i-1}\theta_j\beta_j\right](r-\delta^{NC})+c^E\right)=\frac{r-r_0}{\beta_i}, \tag{161}$$

or equivalently,

$$\delta^{NC}=\frac{r-r_0}{\beta_i}-\frac{l(T+c^E-\tau_i^{NC})}{1+l(1-\sum_{j\le i-1}\theta_j\beta_j)}. \tag{162}$$

Such a δ^{NC} satisfies (132) and $L\left(\left[1-\sum_{j\le i-1}\theta_j\beta_j\right](r-\delta^{NC})-c^E\right)>0$ if and only if:

$$\frac{r-r_0}{\beta_i}-\frac{l(T+c^E-\tau_i^{NC})}{1+l(1-\sum_{j\le i-1}\theta_j\beta_j)}\le r-\frac{c^E}{\sum_{j\ge i}\theta_j\beta_j}, \tag{163}$$

$$\left[1-\sum_{j\le i-1}\theta_j\beta_j\right]\left(r-\frac{r-r_0}{\beta_i}+\frac{l(T+c^E-\tau_i^{NC})}{1+l(1-\sum_{j\le i-1}\theta_j\beta_j)}\right)-c^E<T. \tag{164}$$

or equivalently,

$$c^E\in(\tau_i^{NC}-T,\,\Phi_i^U(T)], \tag{165}$$

which is non-empty if and only if

$$T>\tau_i^{NC}-C_i^U. \tag{166}$$

Combining the above two scenarios, we have that when $c^E\le\max(C_i^U,\Phi_i^U(T))$, the binding constraints are (132) and (135), and the optimal solution is:

$$\delta^{NC}=\frac{r-r_0}{\beta_i}-\frac{l(T+c^E-\tau_i^{NC})^+}{1+l(1-\sum_{j\le i-1}\theta_j\beta_j)}=:\delta_{IR,i}^{NC} \tag{167}$$

and the premium p^{NC} follows directly from (133), i.e.,

$$p^{NC}=c^E+\sum_{j\le i-1}\theta_j\beta_j(r-\delta_{IR,i}^{NC})=:p_{IR,i}^{NC}. \tag{168}$$

The supplier's corresponding payoff is:

$$\Pi^{NC}=r_0-p_{IR,i}^{NC}+\sum_{j<i}\theta_j\left\{(1-\beta_j)r+\beta_j[r-\delta_{IR,i}^{NC}-L(r-\delta_{IR,i}^{NC}-p_{IR,i}^{NC})]-r_0\right\} \tag{169}$$

$$=r_0+\sum_{j<i}\theta_j\left\{(1-\beta_j)r-\beta_jL(r-\delta_{IR,i}^{NC}-p_{IR,i}^{NC})]-r_0\right\}-c^E \tag{170}$$

$$=\Pi_i^E-\frac{\sum_{j<i}\theta_i\beta_il(T+c^E-\tau_i^{NC})^+}{1+l(1-\sum_{j<i}\theta_j\beta_j)}=:\Pi_{IR,i}^{NC}. \tag{171}$$

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

$$T > (1-\bar{\beta})\left(r - \frac{r-r_0}{\beta_i}\right) = \tau_i^{NC} - C_i^U. \tag{172}$$

Under this condition, note that

$$\Phi_i^U(T) = C_i^U + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+(1-\bar{\beta})l}[T - (\tau_i^{NC} - C_i^U)]. \tag{173}$$

Therefore,

$$\max(C_i^U, \Phi_i^U(T)) = C_i^U + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+(1-\bar{\beta})l}[T - (\tau_i^{NC} - C_i^U)]^+, \tag{174}$$

corresponding the boundary that separates the two cases in Lemma C.2. □

Proof of Lemma C.3. By comparing the supplier's payoff under $(p_{IR,i}^{NC}, p_{IR,i}^{NC})$ and (p^{NE}, δ^{NE}), we have:

$$\Pi_{IR,i}^{NC} - \Pi^{NE} = \Pi_i^E - \Pi^{NE} - \frac{\sum_{j<i}\theta_j\beta_j l(T + c^E - \tau_i^{NC})^+}{1 + l(1-\sum_{j<i}\theta_j\beta_j)}. \tag{175}$$

As $\Pi_i^E - \Pi^{NE} = C_i^E - c^E$, $\Pi_{IR,i}^{NC} - \Pi^{NE} \geq 0$ if and only if

$$c^E \leq C_i^E - \frac{l\sum_{j<i}\theta_j\beta_j}{1+l}\left[T - (\tau_i^{NC} - C_i^E)\right]^+ \tag{176}$$

In addition, note that according to Lemma C.2, $(p_{IR,i}^{NC}, p_{IR,i}^{NC})$ is only feasible when

$$c^E \leq C_i^U + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+(1-\bar{\beta})l}[T - (\tau_i^{NC} - C_i^U)]^+ \tag{177}$$

Combining these two conditions, we have that $(p_{IR,i}^{NC}, p_{IR,i}^{NC})$ dominates (p^{NE}, δ^{NE}) if and only if:

$$c^E \leq \min\left(C_i^E - \frac{l\sum_{j<i}\theta_j\beta_j}{1+l}\left[T - (\tau_i^{NC} - C_i^E)\right]^+, C_i^U + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+(1-\bar{\beta})l}[T - (\tau_i^{NC} - C_i^U)]^+\right). \tag{178}$$

Next, by comparing the supplier's payoff under $(p_{IC,i}^{NC}, p_{IC,i}^{NC})$ and (p^{NE}, δ^{NE}), we have:

$$\Pi_{IC,i}^{NC} - \Pi^{NE} = C_i^E - c^E - \left[\frac{(1-\bar{\beta})lc^E + (1 + l\sum_{j<i}\theta_j\beta_j)(c^E - C_i^U)}{l\sum_{j\geq i}\theta_j\beta_j} - T\right]. \tag{179}$$

Therefore, $\Pi_{IC,i}^{NC} \geq \Pi^{NE}$ if and only if:

$$c^E \leq C_i^E - \left[\frac{(1-\bar{\beta})lc^E + (1 + l\sum_{j<i}\theta_j\beta_j)(c^E - C_i^U)}{l\sum_{j\geq i}\theta_j\beta_j} - T\right]. \tag{180}$$

or equivalently,

$$c^E \leq C_i^U + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+l}\left[T - (\tau_i^{NC} - C_i^E)\right]. \tag{181}$$

Combining this condition with the condition that defines the optimality of $(p_{IC,i}^{NC}, \delta_{IC,i}^{NC})$ (relative to $(p_{IR,i}^{NC}, \delta_{IR,i}^{NC})$) in Lemma C.2, i.e., $c^E > C_i^U + \frac{l\sum_{j>i}\theta_j\beta_j}{1+(1-\bar{\beta})l}[T - (\tau_i^{NC} - C_i^U)]^+$, we obtain that $(p_{IC,i}^{NC}, \delta_{IC,i}^{NC})$ is the optimal one among the three if and only if:

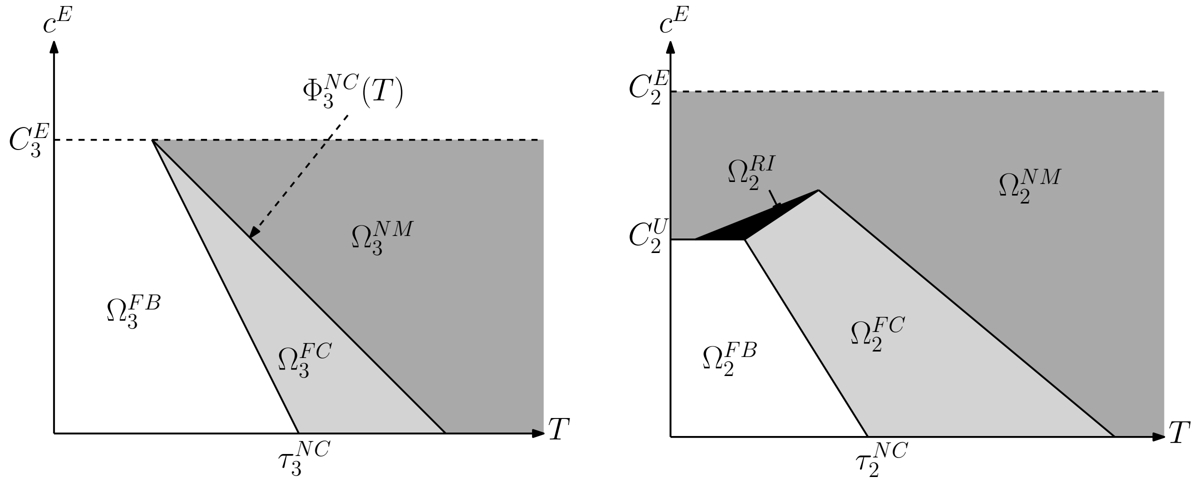
$$c^E \in \left(C_i^U + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+(1-\bar{\beta})l}[T - (\tau_i^{NC} - C_i^U)]^+,\ C_i^U + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+l}\left[T - (\tau_i^{NC} - C_i^E)\right]\right], \tag{182}$$

as desired. □

Figure 6 Illustration of different regions for Proof of Proposition C.1

(a) Comparison between $(p^{NC}_{IC,3}, \delta^{NC}_{IC,3})$, $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$, and (p^{NE}, δ^{NE})

(b) Comparison between $(p^{NC}_{IC,2}, \delta^{NC}_{IC,2})$, $(p^{NC}_{IR,2}, \delta^{NC}_{IR,2})$, and (p^{NE}, δ^{NE})



Proof of Proposition C.1. To identify the optimal contract for $N=3$, we need to consider the following five solutions depending on whether the insurer exerts effort as summarized in Lemma 4 and Lemma C.2, which we summarize as follows.

1. (p^{NE}, δ^{NE}) (Lemma 4): the insurer does not exert effort and the supplier always ships.
2. $(p^{NC}_{IR,3}, p^{NC}_{IR,3})$ (Statement 1 in Lemma C.2 with $i=3$): the insurer exerts effort; the supplier ships at signal $j=1,2$, and the insurer's IR constraint is binding, i.e., the insurer does not extract any information rent.
3. $(p^{NC}_{IC,3}, p^{NC}_{IC,3})$ (Statement 2 in Lemma C.2 with $i=3$): the insurer exerts effort; the supplier ships at signal $j=1,2$, and the insurer's IC constraint is binding, i.e., the insurer extracts some information rent.
4. $(p^{NC}_{IR,2}, p^{NC}_{IR,2})$ (Statement 1 in Lemma C.2 with $i=2$): the insurer exerts effort; the supplier ships at signal $j=1$, and the insurer's IR constraint is binding, i.e., the insurer does not extract any information rent. Note that according to Lemma C.2, this solution is only feasible when $\beta_2 \geq \bar{\beta}$.
5. $(p^{NC}_{IC,2}, p^{NC}_{IC,2})$ (Statement 2 in Lemma C.2 with $i=2$): the insurer exerts effort; the supplier ships at signal $j=1$, and the insurer's IC constraint is binding, i.e., the insurer extracts some information rent. Similarly, according to Lemma C.2, this solution is only feasible when $\beta_2 \geq \bar{\beta}$.

In addition, Lemma C.3 has identified the optimal contract when comparing them in two groups.

1. When comparing only $(p^{NC}_{IC,3}, \delta^{NC}_{IC,3})$, $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$, and (p^{NE}, δ^{NE}), we note that the region that $(p^{NC}_{IC,3}, \delta^{NC}_{IC,3})$ can be optimal is empty, because $C_3^E = \left(1 - \sum_{i=1}^{2} \theta_i \beta_i\right)\left(r - \frac{r-r_0}{\beta_3}\right) = C_3^U$. Therefore, the comparison is between $(p^{NC}_{IC,3}, \delta^{NC}_{IC,3})$ and (p^{NE}, δ^{NE}). Substituting $N=3$ and $i=3$ into Lemma C.3, we have:

(a) $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$ dominates (p^{NE}, δ^{NE}) if and only if $(c^E, T) \in \Omega^{FB}_3 \cup \Omega^{FC}_3$, where

$$\Omega^{FB}_i := \left\{(c^E, T) | c^E \leq C^U_i - (T - (\tau^{NC}_i - C^U_i]^+\right\}; \tag{183}$$

$$\Omega^{FC}_i := \left\{(c^E, T) | c^E \in \left(C^U_i - (T - (\tau^{NC}_i - C^U_i)]^+, \min\left(C^U_i + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+(1-\bar{\beta})l}[T - (\tau^{NC}_i - C^U_i)]^+, \Phi^{NC}_3(T)\right)\right)\right\}; \tag{184}$$

where

$$\Phi^{NC}_i(T) := C^E_i - \frac{l\sum_{j<i}\theta_j\beta_j}{1+l}\left[T - (\tau^{NC}_i - C^E_i)\right]^+ \tag{185}$$

(b) (p^{NE}, δ^{NE}) dominates $(p^{NC}_{IC,3}, \delta^{NC}_{IC,3})$ if and only if if and only if $(c^E, T) \in \Omega^{NM}_3$, where

$$\Omega^{NM}_i := \left\{(c^E, T) | c^E > \min\left(C^U_i + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+l}\left[T - (\tau^{NC}_i - C^E_i)\right]^+, \Phi^{NC}_3(T)\right)\right\}. \tag{186}$$

Regions Ω^{FB}_3, Ω^{FC}_3, and Ω^{NM}_3 are illustrated in Figure 6(a).

2. When comparing only $(p^{NC}_{IC,2}, \delta^{NC}_{IC,2})$, $(p^{NC}_{IR,2}, \delta^{NC}_{IR,2})$, and (p^{NE}, δ^{NE}), the comparison is similar to the previous case, except that the region where $(p^{NC}_{IC,2}, \delta^{NC}_{IC,2})$ can be the optimal one among the three is not empty, because $C^E_2 > C^U_2$. Specifically, we can show that

(a) $(p^{NC}_{IR,2}, \delta^{NC}_{IR,2})$ is the optimal among the three if and only if $(c^E, T) \in \Omega^{FB}_2 \cup \Omega^{FC}_2$, where Ω^{FB}_2 and Ω^{FC}_2 are as defined in (183) and (184) with $i = 2$.

(b) $(p^{NC}_{IC,2}, \delta^{NC}_{IC,2})$ is the optimal among the three if and only if $(c^E, T) \in \Omega^{RI}_2$, where

$$\Omega^{RI}_i := \left\{(c^E, T) | c^E \in \left(C^U_i + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+(1-\bar{\beta})l}[T - (\tau^{NC}_i - C^U_i)]^+, C^U_i + \frac{l\sum_{j\geq i}\theta_j\beta_j}{1+l}\left[T - (\tau^{NC}_i - C^E_i)\right]\right]\right\}. \tag{187}$$

(c) (p^{NE}, δ^{NE}) is the optimal among the three if and only if $(c^E, T) \in \Omega^{NM}_2$, where Ω^{NM}_2 is as defined in (186) with $i = 2$.

Regions Ω^{FB}_2, Ω^{FC}_2, Ω^{RI}_2 and Ω^{NM}_2 are illustrated in Figure 6(b).

With these results, we can identify the optimal non-cancelable contract by considering two cases, $\beta^{FB} > \beta_2$ and $\beta^{FB} \leq \beta_2$.

First, for the case with $\beta^{FB} > \beta_2$ (Panel A in Proposition C.1), we compare the following four possible solutions, $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$, $(p^{NC}_{IC,2}, \delta^{NC}_{IC,2})$, $(p^{NC}_{IR,2}, \delta^{NC}_{IR,2})$, and (p^{NE}, δ^{NE}), and arrive at the following results.

1. For (p^{NE}, δ^{NE}) to be optimal, note that (p^{NE}, δ^{NE}) dominates $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$ if and only if $(c^E, T) \in \Omega^{NM}_3$, and (p^{NE}, δ^{NE}) dominates $(p^{NC}_{IC,2}, \delta^{NC}_{IC,2})$ and $(p^{NC}_{IR,2}, \delta^{NC}_{IR,2})$ if and only if $(c^E, T) \in \Omega^{NM}_2$. Combined, (p^{NE}, δ^{NE}) is the optimal among the four if and only if $(c^E, T) \in \Omega^{NM}$, where

$$\Omega^{NM} := \Omega^{NM}_2 \cap \Omega^{NM}_3. \tag{188}$$

This corresponds to Region NM in Proposition C.1.

2. For $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$ to be optimal, note that when this solution cannot achieve first-best, i.e., $(c^E, T) \notin \Omega^{FB}_3$, $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$ dominates (p^{NE}, δ^{NE}) if and only if $(c^E, T) \in \Omega^{FC}_3$. Therefore, this solution is optimal if and only if it also dominates both $(p^{NC}_{IC,2}, \delta^{NC}_{IC,2})$ and $(p^{NC}_{IR,2}, \delta^{NC}_{IR,2})$, i.e., $(c^E, T) \in \Omega^{FC}_h$ where

$$\Omega^{FC}_h := \left\{(c^E, T) \in \Omega^{FC}_3 | \Pi^{NC}_{IR,3} > \max(\Pi^{NC}_{IR,2}, \Pi^{NC}_{IC,2})\right\}. \tag{189}$$

This corresponds to Region FC in Proposition C.1 (Panel A) and Figure 2(a). In this region, according to Lemma C.2, the supplier incurs financing cost, but the insurer does not extract information rent.

3. When $\beta^{FB} > \beta_2$, either $(p^{NC}_{IC,2}, \delta^{NC}_{IC,2})$ or $(p^{NC}_{IR,2}, \delta^{NC}_{IR,2})$ leads to under-shipping, i.e., the supplier ships only at $i=1$ although it is efficient to ship at $i=1,2$. Based on the above solution, at least one of the these two solutions dominates (p^{NE}, δ^{NE}) if and only $(c^E, T) \in \Omega_2^{FC} \cup \Omega_2^{RI}$. Note that Ω_2^{FB} is irrelevant in this case because for $\beta^{FB} > \beta_2$, we can verify that for any $(c^E, T) \in \Omega_2^{FB}$, we must have $c^E < 0$. Thus, either $(p^{NC}_{IC,2}, \delta^{NC}_{IC,2})$ or $(p^{NC}_{IR,2}, \delta^{NC}_{IR,2})$ can be optimal in this case if and only if $(c^E, T) \in \Omega^{US}$, where

$$\Omega^{US} := \left\{(c^E, T) \in \Omega_2^{FC} \cup \Omega_2^{RI} \,|\, \max(\Pi^{NC}_{IR,2}, \Pi^{NC}_{IC,2}) > \Pi^{NC}_{IR,3}\right\}. \tag{190}$$

This corresponds to Region US in Proposition C.1 and Figure 2(a). Using this definition, we can show that this region is empty when β_2 is sufficiently smaller than β^{FB}. However, when β_2 is very close to β^{FB}, $\theta_1\beta_1 << \theta_2\beta_2$, and l is sufficiently small, Ω^{US} is not empty. When $\Omega^{US} \neq \emptyset$, because $\Omega^{US} \subset \Omega_2^{FC} \cup \Omega_2^{RI}$, the supplier incurs financing cost. When T is sufficiently small, $(c^E, T) \in \Omega_2^{RI}$ and the insurer also extracts information rent.

Similarly, we can identify the optimal contract for $\beta^{FB} \leq \beta_2$ (Panel B in Proposition C.1) by comparing the same four solutions.

1. the region where (p^{NE}, δ^{NE}) is optimal is the same as in the previous case, i.e., $(c^E, T) \in \Omega^{NM}$.

2. for $(p^{NC}_{IR,2}, \delta^{NC}_{IR,2})$ to be optimal, note that when this solution cannot achieve first-best, i.e., $(c^E, T) \notin \Omega_2^{FB}$, $(p^{NC}_{IR,2}, \delta^{NC}_{IR,2})$ dominates both (p^{NE}, δ^{NE}) and $(p^{NC}_{IC,2}, \delta^{NC}_{IC,2})$ if and only if $(c^E, T) \in \Omega_2^{FC}$. Therefore, this solution is optimal when $(c^E, T) \in \Omega_2^{FC}$ and it dominates $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$, i.e.,

$$\Omega_l^{FC} := \left\{(c^E, T) \in \Omega_2^{FC} | \Pi^{NC}_{IR,2} > \Pi^{NC}_{IR,3}\right\}. \tag{191}$$

There exists financing cost, but not information rent.

3. Similarly to the previous case, $(p^{NC}_{IC,2}, \delta^{NC}_{IC,2})$ is optimal if and only if $(c^E, T) \in \Omega_2^{RI}$ and it dominates $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$, i.e., $(c^E, T) \in \Omega^{RI}$.

$$\Omega^{RI} := \left\{(c^E, T) \in \Omega_2^{RI} | \Pi^{NC}_{IC,2} > \Pi^{NC}_{IR,3}\right\}. \tag{192}$$

Both financing cost and information rent exist in this region.

4. for $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$ to be optimal, we note that $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$ dominates (p^{NE}, δ^{NE}) if and only if $(c^E, T) \in \Omega_3^{FB} \cup \Omega_3^{FC}$. Note that $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$ is relevant in Ω_3^{FB} because $\Omega_3^{FB} \not\subset \Omega_2^{FB}$ and $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$ may dominates other possible solutions when $(c^E, T) \notin \Omega_2^{FB}$. By further comparing $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$ with both $(p^{NC}_{IC,2}, \delta^{NC}_{IC,2})$ and $(p^{NC}_{IR,2}, \delta^{NC}_{IR,2})$ in this region, we have that $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$ is the optimal non-cancelable contract if and only if $(c^E, T) \in \Omega^{OS}$ where

$$\Omega^{OS} := \left\{(c^E, T) \in \Omega_3^{FB} \cup \Omega_3^{FC} | \Pi^{NC}_{IR,3} > \max(\Pi^{NC}_{IR,2}, \Pi^{NC}_{IC,2})\right\}. \tag{193}$$

In this case, the insurer never extracts information rent. However, when T is sufficiently large, $(c^E, T) \in \Omega_3^{FC}$, the supplier incurs financing costs.

The above defined regions Ω_l^{FC}, Ω^{OS}, and Ω^{RI} are the ones in Panel B of the proposition. □

Proof of Lemma C.4. The supplier's payoff (118) follows from (C-OBJ) with $i^C = j_1$, $i^{CC} = j_2$ and $i^{CN} = j_3$. With the same substitution, (119)–(122) follow directly from (C-IC1) – (C-IR) in Lemma 6. By the definition of $\beta^C = \frac{f^C}{r-\delta^C}$, (123) – (124) jointly determine that $\beta^C \in [\beta_{j_1-1}, \beta_{j_1})$, i.e., $i^C = j_1$. Finally, (125) and (126) determine that $i^{CC} = j_2$ and $i^{CN} = j_3$, respectively. □

Proof of Lemma C.5. We first show that (127) is necessary for such a cancelable contract to be feasible. Based on Lemma 6 and Lemma C.4, a cancelable contract with $i^C = 2$ and $i^{CN} = 3$ is feasible if and only if the following set of inequalities has a solution.

$$\beta^{CN} \geq \bar{\beta} \tag{194}$$

$$\bar{\beta}(r-\delta^C) \geq c^E + \theta_1\beta_1(r-\delta^C) + \sum_{i\in[2,3]} \theta_i f^C \tag{195}$$

$$f^C \geq c^E + \theta_1\beta_1(r-\delta^C) + \sum_{i\in[2,3]} \theta_i f^C \tag{196}$$

$$p^C \geq c^E + \theta_1\beta_1(r-\delta^C) + \sum_{i\in[2,3]} \theta_i f^C \tag{197}$$

$$f^C < \beta_2(r-\delta^C) \tag{198}$$

$$f^C \geq \beta_1(r-\delta^C) \tag{199}$$

$$\beta^{CN} > \beta_3 \tag{200}$$

As $p^C \geq f^C$, given (196), (197) is redundant. When (200) holds, (194) becomes redundant. Further, when (196) holds, (199) is redundant. Therefore, the above set of inequalities can be simplified as:

$$f^C \leq \frac{(\theta_2\beta_2 + \theta_3\beta_3)(r-\delta^C) - c^E}{\theta_2+\theta_3} \tag{201}$$

$$f^C \geq \frac{c^E}{\theta_1} + \beta_1(r-\delta^C) \tag{202}$$

$$f^C < \beta_2(r-\delta^C) \tag{203}$$

$$\beta^{CN} > \beta_3 \tag{204}$$

Note that (201) and (202) can hold jointly if and only if

$$\frac{(\theta_2\beta_2 + \theta_3\beta_3)(r-\delta^C) - c^E}{\theta_2+\theta_3} \geq \frac{c^E}{\theta_1} + \beta_1(r-\delta^C), \tag{205}$$

or equivalently,

$$c^E \leq \theta_1(\bar{\beta} - \beta_1)(r-\delta^C). \tag{206}$$

Similarly, (202) and (203) can hold jointly if and only if:

$$c^E \leq \theta_1(\beta_2 - \beta_1)(r-\delta^C). \tag{207}$$

Combining (206) and (207), and setting $\delta^C = 0$, which makes both constraints the least stringent, leads to (127).

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 $i = 1, 2$, but 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., (128), allows the supplier to achieve this payoff as long as (127) is satisfied.

1. If the supplier ships at $i=1$. According to Lemma 1, the best possible payoff he can receive is Π_2^E. Next, note that under the contract (128), the supplier has no incentive to ship at $i=2$ when $T>\left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right)r$. And in this region, under the contract (128), her payoff is indeed Π_2^E. Therefore, (128) is optimal.

2. If the supplier ships at $i=1,2$, as the shipment is uninsured at $i=2$, the best possible payoff he can receive is $\Pi_3^E-\theta_2\beta_2 lT$. Symmetrical to the previous case, the supplier has the incentive to ship at $i=2$ when $T\le\left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right)r$. And in this region, under the contract (128), her payoff is indeed $\Pi_3^E-\theta_2\beta_2 lT$. Therefore, (128) is optimal.

Finally, note that the contract (128) has $\delta^C=0$, thus, it satisfies (194) – (200) under (127). Thus, this contract always induces the specific cancelation and shipping decisions as specified in the lemma as long as (127) is satisfied. □

Proof of Lemma C.6. Note that if the insurer only cancels at $i=3$, we must have $i^C=i^{CN}=3$ (if not, i.e., $i^{CN}<3$, then the insurer does not have the incentive to cancel at $i=3$.) and $i^{CC}<3$ (because if $i^{CC}=3$, then the supplier ships under all signals, and hence the insurer has no incentive to exert effort). By imposing the above i^C, i^{CN} and i^{CC}, we re-write the optimization problem in Lemma C.4 as follows:

$$\max_{p^C,\delta^C\in[0,r],f^C\le p^C} r_0-p^C+\sum_{i\le 2}\theta_i[(r-r_0)-\beta_i(\delta^C+L(r-p^C-\delta^C))]+\theta_3 f^C. \tag{208}$$

$$\beta^{CN}\ge\bar\beta \tag{209}$$

$$\bar\beta(r-\delta^C)\ge c^E+\sum_{i\le 2}\theta_i\beta_i(r-\delta^C)+\theta_3 f^C \tag{210}$$

$$f^C\ge c^E+\sum_{i\le 2}\theta_i\beta_i(r-\delta^C)+\theta_3 f^C \tag{211}$$

$$p^C\ge c^E+\sum_{i\le 2}\theta_i\beta_i(r-\delta^C)+\theta_3 f^C \tag{212}$$

$$f^C<\beta_3(r-\delta^C) \tag{213}$$

$$f^C\ge\beta_2(r-\delta^C) \tag{214}$$

$$\beta^{CN}\ge\beta_3 \tag{215}$$

$$\beta^{CC}\le\beta_3 \tag{216}$$

Note that by the definition of β^{CC}, we always have $\beta^{CC}<\beta^{FB}<\beta_3$. Thus, (216) is redundant. Further, given $p^C\ge f^C$ and (211), (212) becomes redundant. Given (215), (209) is redundant. When (210) holds, (213) becomes redundant. Finally, note that p^C only appears in (208), (215), and in the constraint $f^C\le p^C$. As a smaller p^C improves the objective function and loosens (215), under the optimal solution, the constraint $f^C\le p^C$ must be binding, i.e. $p^C=f^C$. Consolidating all the above steps, we can simplify (208) – (216) into the following equations.

$$\max_{\delta^C\in[0,r],f^C} r_0-f^C+\sum_{i\le 2}\theta_i[(r-r_0)-\beta_i(\delta^C+L(r-f^C-\delta^C))]+\theta_3 f^C. \tag{217}$$

$$f^C\le\beta_3(r-\delta^C)-\frac{c^E}{\theta_3} \tag{218}$$

$$f^C\ge\frac{c^E+\sum_{i\le 2}\theta_i\beta_i(r-\delta^C)}{\theta_1+\theta_2} \tag{219}$$

$$f^C \geq \beta_2(r - \delta^C) \tag{220}$$

$$\beta^{CN} \geq \beta_3 \tag{221}$$

Note that for any given δ^C, the objective function decreases in f^C. In addition, as f^C decreases, both (218) and (221), which can be re-written as $\frac{r-r_0}{\delta^C+L(r-\delta^C-f^C)} \geq \beta_3$, are relaxed. Therefore, at the optimal f^C, at least one of (219) and (220) will be binding. By comparing the two conditions, we can see that the binding one depends on the magnitude of δ^C. Specifically, note that

$$\frac{c^E + \sum_{i\leq 2}\theta_i\beta_i(r-\delta^C)}{\theta_1+\theta_2} \geq \beta_2(r-\delta^C) \tag{222}$$

is equivalent to

$$\delta^C \geq r - \frac{c^E}{\theta_1(\beta_2-\beta_1)}. \tag{223}$$

When this condition is satisfied, (219) is the binding constraint, i.e., the insurer does not extract rent. However, the supplier may incur financing cost. Otherwise, (220) 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: For $\delta^C \geq r - \frac{c^E}{\theta_1(\beta_2-\beta_1)}$, (219) is the binding constraint, and it can be re-written as $f^C = \frac{c^E+\sum_{i=1}^2\theta_i\beta_i(r-\delta^C)}{\sum_{i=1}^2\theta_i}$, and (217) – (221) can be re-written as follows:

$$\max_{\delta^C\in[0,r]} \quad \Pi_3^E - \sum_{i=1}^2 \theta_i\beta_i L\left(\left[1-\frac{\sum_{i=1}^2\theta_i\beta_i}{\sum_{i=1}^2\theta_i}\right](r-\delta^C) - \frac{c^E}{\sum_{i=1}^2\theta_i}\right) \tag{224}$$

$$\text{s.t.} \quad \delta^C \leq r - \frac{c^E}{\theta_3(\beta_3-\bar{\beta})} \tag{225}$$

$$\delta^C \geq r - \frac{c^E}{\theta_1(\beta_2-\beta_1)} \tag{226}$$

$$\delta^C + L\left(\left[1-\frac{\sum_{i=1}^2\theta_i\beta_i}{\sum_{i=1}^2\theta_i}\right](r-\delta^C) - \frac{c^E}{\sum_{i=1}^2\theta_i}\right) \leq \frac{r-r_0}{\beta_3} \tag{227}$$

Note that the difference between (224) and the first-best (Π_3^E) is the potential financing cost. In addition, by comparing (225) and (226), we note that the two constraints can jointly hold if and only if

$$\theta_3(\beta_3-\bar{\beta}) \geq \theta_1(\beta_2-\beta_1), \tag{228}$$

or equivalently,

$$\beta_2 \leq \bar{\beta}. \tag{229}$$

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 cancelation and shipping policies. In the original optimization problem, the reason lies in the fact that when (211) is binding, (210) and (214) cannot hold jointly if $\beta_2 > \bar{\beta}$.

On the other hand, when $\beta_2 \leq \bar{\beta}$, note that the objective function decreases in δ^C. Therefore, the optimal solution corresponds to the smallest δ^C that satisfies (225) – (227). Note that both (225) and (227) are loosened for a smaller δ^C, hence, the optimal solution, if feasible, is:

$$\delta^C = \left(r - \frac{c^E}{\theta_1(\beta_2-\beta_1)}\right)^+. \tag{230}$$

We can verify that under this deductible and $\beta_2 \le \bar{\beta}$, (225) always holds. To check whether (227) holds under this contract, we further consider two scenarios, depending on whether $\delta^C = 0$, i.e., $r - \frac{c^E}{\theta_1(\beta_2-\beta_1)} \le 0$.

Scenario I.A: For $c^E \ge \theta_1(\beta_2-\beta_1)r$, $\delta^C = 0$. We can also verify that (227) holds under all T that satisfies Assumption 2. Thus, the corresponding optimal contract is:

$$\delta^C = 0, \quad p^C = f^C = \frac{c^E + \sum_{i=1}^2 \theta_i\beta_i r}{\sum_{i=1}^2 \theta_i}, \tag{231}$$

and the supplier's payoff is Π_3^E, the first-best benchmark.

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

$$\delta^C = r - \frac{c^E}{\theta_1(\beta_2-\beta_1)}; \quad p^C = f^C = \frac{\beta_2 c^E}{\theta_1(\beta_2-\beta_1)}. \tag{232}$$

This solution is feasible if and only if it satisfies (227), or equivalently,

$$r - r_0 \ge \beta_3\left[r - \frac{c^E}{\theta_1(\beta_2-\beta_1)} + L\left(\frac{(1-\beta_2)c^E}{\theta_1(\beta_2-\beta_1)}\right)\right]. \tag{233}$$

Note that if this solution is infeasible, then no solution under which (219) is binding will be feasible.

Depending on whether the supplier can avoid financing cost, i.e., $T \le \frac{(1-\beta_2)c^E}{\theta_1(\beta_2-\beta_1)}$, we further consider two cases.

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

$$c^E \ge \frac{\theta_1(\beta_2-\beta_1)}{(1-\beta_2)}T, \tag{234}$$

the supplier can avoid financing cost. Under this condition, (227) holds if and only if:

$$c^E \ge \theta_1(\beta_2-\beta_1)\left(r - \frac{r-r_0}{\beta_3}\right). \tag{235}$$

Therefore, we have the following two cases.

1. the above contract achieves first-best Π_3^E when:

$$c^E \ge \theta_1(\beta_2-\beta_1)\max\left(r - \frac{r-r_0}{\beta_3}, \frac{T}{1-\beta_2}\right). \tag{236}$$

2. the above contract is infeasible when:

$$c^E \in \left(\frac{\theta_1(\beta_2-\beta_1)}{1-\beta_2}T,\, \theta_1(\beta_2-\beta_1)\left(r - \frac{r-r_0}{\beta_3}\right)\right). \tag{237}$$

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

$$c^E \le \frac{\theta_1(\beta_2-\beta_1)}{(1-\beta_2)}T, \tag{238}$$

$\beta^{CN} \ge \beta_3$ can be re-written as:

$$r - r_0 \ge \beta_3\left[r + lT - \frac{[1+(1-\beta_2)l]c^E}{\theta_1(\beta_2-\beta_1)}\right], \tag{239}$$

or equivalently,

$$c^E \ge \frac{\theta_1(\beta_2-\beta_1)[r - \frac{r-r_0}{\beta_3} + lT]}{1+(1-\beta_2)l}. \tag{240}$$

Note that (238) and (240) jointly hold if and only if $T \ge (1-\beta_2)\left(r - \frac{r-r_0}{\beta_3}\right)$. Therefore, we have two cases:

1. for $T \geq (1-\beta_2)\left(r - \frac{r-r_0}{\beta_3}\right)$, the above solution is feasible, and the supplier's payoff is $\Pi_3^E - \sum_{i=1}^2 \theta_i\beta_i l\left(T - \frac{(1-\beta_2)c^E}{\theta_1(\beta_2-\beta_1)}\right)$.
2. $T \geq (1-\beta_2)\left(r - \frac{r-r_0}{\beta_3}\right)$, the above solution is infeasible.

Combining Scenario I.A, Scenario I.B.a (two sub-cases) and Scenario I.B.b (two sub-cases), we summarize the optimal contract in Scenario I as follows.

1. The contract achieves first-best ($\Pi^{III} = \Pi_3^E$) when

$$c^E \geq \theta_1(\beta_2-\beta_1)\max\left(r - \frac{r-r_0}{\beta_3}, \frac{T}{1-\beta_2}\right). \tag{241}$$

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

$$c^E < \frac{\theta_1(\beta_2-\beta_1)}{1-\beta_2}T \text{ and } T \geq (1-\beta_2)\left(r - \frac{r-r_0}{\beta_3}\right). \tag{242}$$

   and the supplier's payoff is:

$$\Pi^{III} = \Pi_3^E - \sum_{i=1}^2 \theta_i\beta_i l\left(T - \frac{(1-\beta_2)c^E}{\theta_1(\beta_2-\beta_1)}\right), \tag{243}$$

3. The contract is infeasible when:

$$c^E < \theta_1(\beta_2-\beta_1)\left(r - \frac{r-r_0}{\beta_3}\right) \text{ and } T < (1-\beta_2)\left(r - \frac{r-r_0}{\beta_3}\right). \tag{244}$$

Scenario II: For $\delta^C \leq r - \frac{c^E}{\theta_1(\beta_2-\beta_1)}$, (220) is binding. The binding constraint ensures that the insurer will not cancel coverage at $i=2$. To achieve this, the insurer may extract information rent. Under this scenario, we have:

$$p^C = f^C = \beta_2(r-\delta^C). \tag{245}$$

Substituting the above expression of p^C and f^C into (217) – (221) leads to:

$$\max_{\delta^C\in[0,r]} \quad \Pi_3^E - \left[\theta_1(\beta_2-\beta_1)(r-\delta^C) - c^E\right] - \sum_{i=1}^2 \theta_i\beta_i l[T-(1-\beta_2)(r-\delta^C)]^+ \tag{246}$$

$$\text{s.t.} \quad \delta^C \leq r - \frac{c^E}{\theta_3(\beta_3-\beta_2)} \tag{247}$$

$$\delta^C \leq r - \frac{c^E}{\theta_1(\beta_2-\beta_1)} \tag{248}$$

$$\delta^C \leq \frac{r-r_0}{\beta_3} - \frac{l\left[T-(1-\beta_2)\left(r-\frac{r-r_0}{\beta_3}\right)\right]^+}{1+l(1-\beta_2)} \tag{249}$$

As shown, the objective function equals to the first-best payoff Π_3^E minus the information rent surrendered to the insurer, and then minus the expected financing cost. Note that the information rent, $\theta_1(\beta_2-\beta_1)(r-\delta^C)-c^E$, decreases in δ^C, while the financing cost is constant in δ^C for $\delta^C \leq r - \frac{T}{1-\beta_2}$, and increasing in δ^C for $\delta^C > r - \frac{T}{1-\beta_2}$. Combining these two forces, as δ^C increases from zero, the financing cost initially remains at zero, and hence the objective function increases until $\delta^C = r - \frac{T}{1-\beta_M}$.[19] For a greater δ^C, the supplier incurs financing cost, and

$$\frac{d\Pi}{d\delta^C} = \theta_1(\beta_2 - \beta_1) - l\sum_{i=1}^{2}\theta_i\beta_i(1-\beta_2), \tag{250}$$

which is positive if and only if

$$l < l_h := \frac{\theta_1(\beta_2 - \beta_1)}{\sum_{i=1}^{2}\theta_i\beta_i(1-\beta_2)}. \tag{251}$$

Therefore, the optimal δ^C follows two cases depending whether l is greater than l_h.

1. For $l \le l_h$, as δ^C 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 (247) – (249) is binding. Equivalently,

$$\delta^C = \min\left(r - \frac{c^E}{\theta_3(\beta_3 - \beta_2)},\ r - \frac{c^E}{\theta_1(\beta_2 - \beta_1)},\ \frac{r - r_0}{\beta_3} - \frac{l\left[T - (1-\beta_2)\left(r - \frac{r-r_0}{\beta_3}\right)\right]^+}{1 + l(1-\beta_2)}\right). \tag{252}$$

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

$$\delta^C = \min\left(r - \frac{T}{1-\beta_2},\ r - \frac{c^E}{\theta_3(\beta_3 - \beta_2)},\ r - \frac{c^E}{\theta_1(\beta_2 - \beta_1)},\ \frac{r - r_0}{\beta_3} - \frac{l\left[T - (1-\beta_2)\left(r - \frac{r-r_0}{\beta_3}\right)\right]^+}{1 + l(1-\beta_2)}\right). \tag{253}$$

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 δ^C and the corresponding payoff in the format in Lemma C.6.

First, consider the case with $\beta_2 \le \bar{\beta}$ (Solution IIl.L in Lemma C.6). Note that in this case, (247) is tighter than (248). Depending on the range of c^E, T, and l, we further consider the following cases.

1. When $c^E \ge \theta_1(\beta_2 - \beta_1)\max\left(r - \frac{r-r_0}{\beta_3}, \frac{T}{1-\beta_2}\right)$, according to Scenario I, the supplier can achieve first-best. This corresponds to Solution III.L.1.
2. When $c^E < \theta_1(\beta_2 - \beta_1)\left(r - \frac{r-r_0}{\beta_3}\right)$ and $T \le (1-\beta_2)\left(r - \frac{r-r_0}{\beta_3}\right)$, Scenario I is infeasible. Therefore, we only need to consider the optimal solution in Scenario II. By considering (252) and (253), we have that $\delta^C = \frac{r-r_0}{\beta_3}$, and $\Pi^{III} = \Pi_3^E - \left[\theta_1(\beta_2 - \beta_1)\left(r - \frac{r-r_0}{\beta_3}\right) - c^E\right]$. Note that the inefficiency, $\Pi_3^E - \Pi^{III}$, increases in c^E. This corresponds to Solution III.L.2.
3. When $c^E < \frac{\theta_1(\beta_2-\beta_1)T}{1-\beta_2}$ and $T > (1-\beta_2)\left(r - \frac{r-r_0}{\beta_3}\right)$, consider the following two cases, which correspond to the two cases in Solution III.L.3.

[19] We can verify that $\delta^C = 0$ is a feasible solution to the range of c^E that we are interested, i.e., $c^E \le C_3^E := \theta_3(\beta_3 - \beta^{FB})r$ for $\beta_2 > \bar{\beta}$, and $c^E \le \theta_1(\beta_2 - \beta_1)r$ for $\beta_2 \le \bar{\beta}$. The second set of conditions comes from the fact that when $\beta_2 \le \bar{\beta}$, the optimal solution in Scenario I.A above can achieve first-best, hence it is unnecessary to consider other solutions.

(a) when $l > l_h$, the solution in Scenario II follows (253). By comparing the four scenarios, we can see that the binding one is $\delta^C = r - \frac{T}{1-\beta_2}$. In this case, the supplier can avoid financing cost, and her payoff:

$$\Pi^{III} = \Pi_3^E - \left(\frac{\theta_1(\beta_2-\beta_1)T}{1-\beta_2} - c^E\right). \tag{254}$$

Comparing this with the supplier's payoff under the optimal contract in Scenario I (243), we have:

$$\Pi_3^E - \left(\frac{\theta_1(\beta_2-\beta_1)T}{1-\beta_2} - c^E\right) - \Pi_3^E + l\sum_{i=1}^{2}\theta_i\beta_i\left(T - \frac{(1-\beta_2)c^E}{\theta_1(\beta_2-\beta_1)}\right) \tag{255}$$

$$= (l-l_h)\sum_{i=1}^{2}\theta_i\beta_i\left(T - \frac{(1-\beta_2)c^E}{\theta_1(\beta_2-\beta_1)}\right) \geq 0. \tag{256}$$

Thus, the solution in Scenario II, i.e., $\delta^C = r - \frac{T}{1-\beta_2}$, 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., (252), can be simplified into:

$$\delta^C = \min\left(r - \frac{c^E}{\theta_1(\beta_2-\beta_1)},\ r - \frac{r - \frac{r-r_0}{\beta_3} + lT}{1+(1-\beta_2)l}\right). \tag{257}$$

Consider the following two cases. First, when $c^E \in \left[\frac{\theta_1(\beta_2-\beta_1)\left[r-\frac{r-r_0}{\beta_3}+lT\right]}{1+(1-\beta_2)l}, \frac{\theta_1(\beta_2-\beta_1)T}{1-\beta_2}\right)$, following similar analysis, we can show that the optimal contract is the one under Scenario II, i.e., $\delta^C = r - \frac{c^E}{\theta_1(\beta_2-\beta_1)}$, the same as in Scenario I. Therefore, the supplier's payoff is the same as in (243). This corresponds to Solution III.L.3(a) in the lemma.

Second, when $c^E < \frac{\theta_1(\beta_2-\beta_1)\left[r-\frac{r-r_0}{\beta_3}+lT\right]}{1+(1-\beta_2)l}$, the optimal solution under Scenario II is $\delta^C = r - \frac{r-\frac{r-r_0}{\beta_3}+lT}{1+(1-\beta_2)l}$. And the corresponding payoff is

$$\Pi^{III} = \Pi_3^E - \left[\theta_1(\beta_2-\beta_1)(r-\delta^C) - c^E\right] - \sum_{i=1}^{2}\theta_i\beta_i l[T-(1-\beta_2)(r-\delta^C)]^+ \tag{258}$$

$$= \Pi_3^E + c^E - \frac{\theta_1(\beta_2-\beta_1)\left(r - \frac{r-r_0}{\beta_3} + lT\right)}{1+(1-\beta_2)l} - \sum_{i=1}^{2}\theta_i\beta_i l\left[\frac{T-(1-\beta_2)\left(r-\frac{r-r_0}{\beta_3}\right)}{1+(1-\beta_2)l}\right], \tag{259}$$

with some algebra, we can show that this payoff is always lower than the supplier's payoff under Scenario I, i.e., (243).

Combining these two cases, we can show that for $l \leq l_h$, $\delta^C = r - \frac{c^E}{\theta_1(\beta_2-\beta_1)}$, and the supplier's payoff follows (243).

Next, consider the case with $\beta_2 \leq \bar{\beta}$ (Solution III.H in Lemma C.6). Note that in this case, (248) is tighter than (247). In addition, Scenario I is infeasible. Therefore, we only need to consider the solution in Scenario II, as governed by (252) and (253). Depending on the range of c^E, T, and l, we further consider the following cases.

1. When $c^E \geq \theta_3(\beta_3-\beta_2)\max\left(r - \frac{r-r_0}{\beta_3}, \frac{T}{1-\beta_2}\right)$, regardless of l, we have: $\delta^C = r - \frac{c^E}{\theta_3(\beta_3-\beta_2)}$, and the supplier's payoff, following (246), is:

$$\Pi^{III} = \Pi_3^E - \left[\theta_1(\beta_2-\beta_1)(r-\delta^C) - c^E\right] - \sum_{i=1}^{2}\theta_i\beta_i l[T-(1-\beta_2)(r-\delta^C)]^+ = \Pi_3^E - \frac{(\bar{\beta}-\beta_2)c^E}{\theta_3(\beta_3-\beta_2)}, \tag{260}$$

corresponding to Solution III.H.1.

2. When $c^E < \theta_3(\beta_3-\beta_2)\left(r-\frac{r-r_0}{\beta_3}\right)$ and $T \le (1-\beta_2)\left(r-\frac{r-r_0}{\beta_3}\right)$, by considering (252) and (253), we have that $\delta^C = \frac{r-r_0}{\beta_3}$, and

$$\Pi^{III} = \Pi_3^E - \left[\theta_1(\beta_2-\beta_1)\left(r-\frac{r-r_0}{\beta_3}\right) - c^E\right]. \tag{261}$$

   This corresponds to Solution III.H.2.

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

   (a) when $l > l_h$, the solution in Scenario II follows (253). By comparing the four scenarios, we can see that the binding one is $\delta^C = r - \frac{T}{1-\beta_2}$. In this case, the supplier can avoid financing cost, and her payoff is:

$$\Pi_3^E - \left(\frac{\theta_3(\beta_3-\beta_2)T}{1-\beta_2} - c^E\right). \tag{262}$$

   (b) when $l \le l_h$, the optimal contract under Scenario II, i.e., (252), can be simplified into:

$$\delta^C = \min\left(r - \frac{c^E}{\theta_3(\beta_3-\beta_2)},\ r - \frac{r-\frac{r-r_0}{\beta_3}+lT}{1+(1-\beta_2)l}\right). \tag{263}$$

   Therefore, consider the following two cases.

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

$$\Pi^{III} = \Pi_3^E - \frac{(\beta_2-\bar{\beta})c^E}{\theta_3(\beta_3-\beta_2)} - \sum_{i=1}^{2}\theta_i\beta_i l\left[T - \frac{(1-\beta_2)c^E}{\theta_3(\beta_3-\beta_2)}\right]. \tag{264}$$

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

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

$$\Pi^{III} = \Pi_3^E - \left[\theta_1(\beta_2-\beta_1)(r-\delta^C) - c^E\right] - \sum_{i=1}^{2}\theta_i\beta_i l[T-(1-\beta_2)(r-\delta^C)]^+ \tag{265}$$

$$= \Pi_3^E - \left[\frac{\theta_1(\beta_2-\beta_1)\left(r-\frac{r-r_0}{\beta_3}+lT\right)}{1+(1-\beta_2)l} - c^E\right] - \sum_{i=1}^{2}\theta_i\beta_i l\left[\frac{T-(1-\beta_2)\left(r-\frac{r-r_0}{\beta_3}\right)}{1+(1-\beta_2)l}\right], \tag{266}$$

   corresponding to Solution III.H.3(a). □

Proof of Lemma C.7. In addition to the cancelation policies covered in Lemmas C.5 and C.6, cancelable contracts under which the insurer exerts effort, as summarized in Lemma 6, may induce the following three types of cancelation policies.

1. If the insurer cancels only at $i = 2$, which leads to $i^C = 2$ and $i^{CN} = 2$. In terms of the supplier's shipping decision, by applying Lemma 5, we can show that other the following scenarios are possible.

   (a) the supplier ships only at $i = 1$, which leads to $i^{CC} = 1$.

   (b) the supplier ships at $i = 1, 2$, which leads to $i^{CC} = 2$.

To see why other shipping policies are not possible, note that according to Lemma 5, 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 $i^C=1$ and $i^{CN}=2$. In terms of the supplier's shipping decision, there are two possible scenarios.
   (a) the supplier ships only at $i=1$, which leads to $i^{CC}=1$.
   (b) the supplier ships at $i=1,2$, which leads to $i^{CC}=2$.
3. If the insurer cancels at only $i=1$, which leads to $i^C=1$ and $i^{CN}=1$, which also leads to $i^{CC}=1$. 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 Π_2^E. By comparing this with the optimal contract in Lemmas C.5 and C.6, we note that:
   (a) when $\beta_2<\bar{\beta}$, we further consider two cases.
      i. when $c^E\geq\theta_1(\beta_2-\beta_1)\max\left(r-\frac{r-r_0}{\beta_3},\frac{T}{1-\beta_2}\right)$, according to Lemma C.6 (Solution III.L.1), there exists a contract that can achieve the first-best payoff Π_3^E, which is greater than Π_2^E.
      ii. when $c^E<\theta_1(\beta_2-\beta_1)\max\left(r-\frac{r-r_0}{\beta_3},\frac{T}{1-\beta_2}\right)$, we can verify that the solution in Lemma C.5 is feasible. Also, note that the payoff in Lemma C.5 is greater than or equal to the upper bound Π_2^E.
   (b) when $\beta_2\geq\bar{\beta}$, we can verify that the solution in Lemma C.5 is feasible, and the corresponding payoff is greater than or equal to the upper bound Π_2^E.
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 $\Pi_3^E-\theta_2\beta_2 lT$. Similar to the previous case, we can show that such contract is (weakly) dominated by those in Lemmas C.5 and C.6.

Combining the above two cases, we conclude that we do not need to consider cancelable contracts other than those studied in Lemmas C.5 and C.6. □

Proof of Corollary C.1. Following the proof in Proposition 3, to characterize $\Phi_C(T)$, we only need to compare the optimal contract in Lemma C.5 and Lemma C.6. In particular, as $\bar{\beta}\geq\beta_2$, and $l<l_h$, within Solution III, the relevant ones are Solution III.L.1, III.L.2, and III.L.3(a). These three scenarios and the corresponding region that they are relevant is illustrated in Figure 5(c). To compare the relevant solutions, consider the following three ranges of T.

1. when $T \le (1-\beta_2)\left(r - \frac{r-r_0}{\beta_3}\right)$, the comparison is between Solution II.1 and Solution III.L.2. By comparing the two efficiency losses (as defined in the proof of Proposition 3), Δ^{II} and Δ^{III}, Solution II.1 (Region UI) is preferred if and only if:

$$\Delta^{II} - \Delta^{III} \le 0 \Leftrightarrow l\theta_2\beta_2 T - \left[\theta_1(\beta_2-\beta_1)\left(r - \frac{r-r_0}{\beta_3}\right) - c^E\right] \le 0. \tag{267}$$

$$\Leftrightarrow c^E \le \theta_1(\beta_2-\beta_1)\left(r - \frac{r-r_0}{\beta_3}\right) - l\theta_2\beta_2 T. \tag{268}$$

Note that at $T = (1-\beta_2)\left(r - \frac{r-r_0}{\beta_3}\right)$, as $l \le l_h$, $\theta_1(\beta_2-\beta_1)\left(r - \frac{r-r_0}{\beta_3}\right) - l\theta_2\beta_2 T \ge 0$. Thus, by the definition of $\Phi_C(T)$ in the proof of Proposition 3,

$$\Phi_C(T) := \theta_1(\beta_2-\beta_1)\left(r - \frac{r-r_0}{\beta_3}\right) - l\theta_2\beta_2 T > 0, \tag{269}$$

in this region.

2. when $T \in \left((1-\beta_2)\left(r - \frac{r-r_0}{\beta_3}\right), \left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right)r\right)$, the comparison is between Solution II.1 and Solution III.L.3(a). Solution II.1 is preferred if and only if:

$$\Delta^{II} - \Delta^{III} \le 0 \Leftrightarrow l\theta_2\beta_2 T - \sum_{i=1}^{2}\theta_i\beta_i l\left(T - \frac{(1-\beta_2)c^E}{\theta_1(\beta_2-\beta_1)}\right) \le 0 \tag{270}$$

$$\Leftrightarrow c^E \le \theta_1\beta_1 l_h T =: \Phi_C(T). \tag{271}$$

3. when $T \ge \left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right)r$, the comparison is between Solution II.2 and Solution III.L.3(a). Solution II.2 is preferred if and only if:

$$\Delta^{II} - \Delta^{III} \le 0 \Leftrightarrow \theta_2(\beta^{FB}-\beta_2)r - \sum_{i=1}^{2}\theta_i\beta_i l\left(T - \frac{(1-\beta_2)c^E}{\theta_1(\beta_2-\beta_1)}\right) \le 0. \tag{272}$$

$$\Leftrightarrow c^E \le \frac{\theta_1(\beta_2-\beta_1)}{(1-\beta_2)}\left[T - \frac{\theta_2(\beta^{FB}-\beta_2)r}{\sum_{i=1}^{2}\theta_i\beta_i l}\right] =: \Phi_C(T). \tag{273}$$

Combining the above three cases leads to the expression of $\Phi_C(T)$ as in (129). Also note that $\Phi_C(T)$ is continuous at $T = \left(\frac{\beta^{FB}-\beta_2}{l\beta_2}\right)r$, between the later two cases. Between the first two cases, we have that at $T = (1-\beta_2)\left(r - \frac{r-r_0}{\beta_3}\right)$,

$$\theta_1(\beta_2-\beta_1)\left(r - \frac{r-r_0}{\beta_3}\right) - l\theta_2\beta_2 T \ge \theta_1\beta_1 l_h T \ge 0, \tag{274}$$

where the equality holds for $l = l_h$. □

Proof of Corollary C.2. The contract on the first line in the table follows directly from the analysis in Scenario I.A.a in the proof of Proposition 4.

For the contract on the second line, , we can verify that the contract with parameters $\delta^{HN} = 0$, $\delta^{HC} = r - T$, and $p^H = f^H = \beta_1 r + \frac{c^E + \theta_2\beta_2(r-T)}{\theta_1}$ satisfies (85) – (93) in the specified region of (c^E, T). Therefore, it can recover the first-best. □

Appendix E: Numerical results with N groups of signals

In the main body of the paper, while we focus on the case with three signal classes ($N = 3$) for ease of exposition, most of our analytical results, except for Propositions 3, 4, and C.1, can be directly generalized to the case with arbitrary N signal classes. To complement the analytical results in the paper, in this appendix, we conduct extensive numerical studies to show that our main insights regarding the structure of the optimal non-cancelable and cancelable contracts, as well as their relative performance, are robust with regards to the number of possible signals.

E.1. Parameter selection

In this experiment, we select the trade credit payment default distribution (β_i, θ_i) by referencing Boissay and Gropp (2013). Using data on trade credit defaults of French firms from 1998–2003, Boissay and Gropp (2013) find that on average 18.5% of firms had a payment default in a quarter, although 16.2% were classified as disagreements with regards to the terms of the bill presented or the quality of the goods, both of which are not covered by TCI. As such, only the remainder (2.3%), which is split among insolvency, illiquidity, or omission, are covered under trade credit insurance. Conversely, 7.2% of firms faced a default in a quarter on average, but this likewise included disagreements. Using these as a reference, we study two scenarios of (β_i, θ_i) as shown in Table E.1. Each scenario includes 10 groups of signals ($N = 10$) with corresponding default rates (β_i) and their respective probabilities (θ_i^K), $K = H, L$. Note that the default risk distribution under Scenario H stochastically dominates that under Scenario L. In other words, the H scenario is on average riskier.

Table 2 Default risk distributions used in numerical experiments

β	2%	5%	10%	15%	20%	30%	40%	50%	75%	100%	$\bar{\beta}$
θ^H	80%	8%	3%	3%	1.5%	1.5%	1%	1%	0.5%	0.5%	5.3%
θ^L	97%	1%	0.5%	0.5%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	2.5%

For the supplier's outside option r_0, we consider three levels: $r_0^H = 96$, $r_0^M = 92$, and $r_0^L = 75$. Relative to the credit price r, which we set to 100 without loss of generality, the corresponding β^{FB} under the three outside option levels are 4%, 8%, and 25% respective. Relative to the notion we use in the main body of the paper, r_0^H is the most attractive outside option, and r_0^L is the least attractive one.

We consider two scenarios for the supplier's financing cost (l): (i) the low scenario with $l = 15\%$, which is on par with the interest rate of business credit cards, and (ii) the high scenario with $l = 100\%$, which represents the case where the supplier has no readily available access to outside financing.[20]

Combining the different levels of θ_i (2 scenarios), r_0 (3 scenarios) and l (2 scenarios), we have 10 cases in total that are consistent with our modeling assumptions.[21] For each of the 10 cases, we analyze 100 levels of c^E in the range $[0, \bar{C}^E]$ where $\bar{C}^E$ is the largest level under which monitoring is efficient. Similarly, we consider

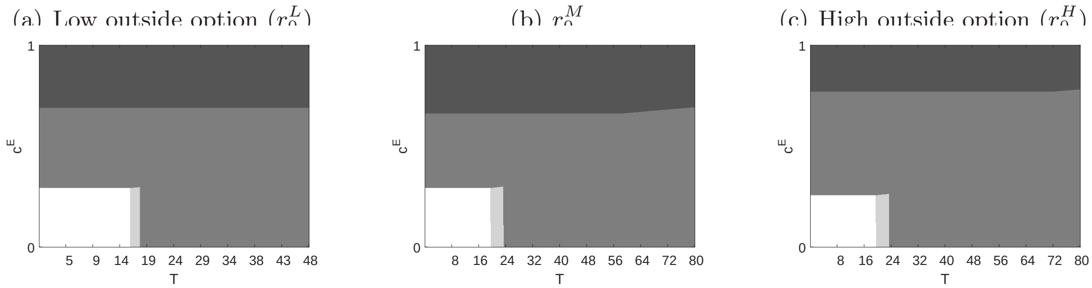
[20] Analysis with financial costs l greater than 100% produces very similar results.

[21] In the main body of the paper, we assume that $\beta^{FB} > \bar{\beta}$ since this captures most realistic settings; however, under the parameters listed above, when the default risk is high (θ^H) *and* the outside option is attractive (r_0^H), we have $\beta^{FB} = 4\% < \bar{\beta}$. Therefore, we omit this combination (for both l levels), resulting in a total of 10 combinations.

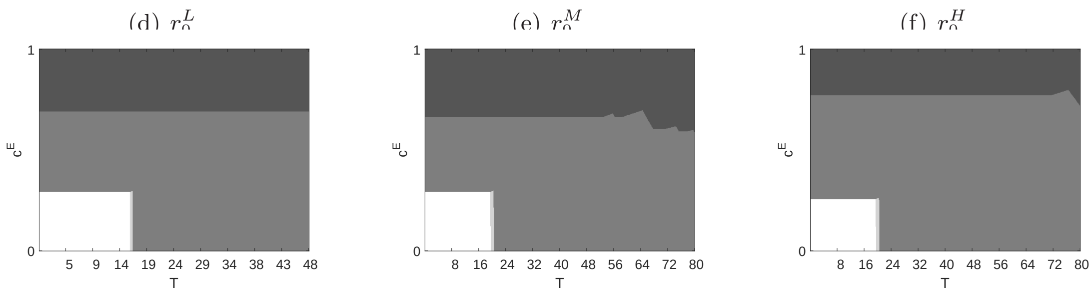
100 levels of the financial constraint T, varying from 0 to $2r_0 - r$, as governed Assumption 2. Combining all levels of θ, l, r_0, c^E, and T, we have in total 100,000 combinations of parameters. For each of the 100,000 scenarios, we first compute the first-best benchmark following Lemma 1, and then identify and compare the optimal non-cancelable and cancelable contracts. We present the results in the following three subsections.

Figure 7 **Numerical results for the optimal non-cancelable contract with $N = 10$ signal classes and financing cost l under various outside options (r_0) and expected default risk (θ^L).**

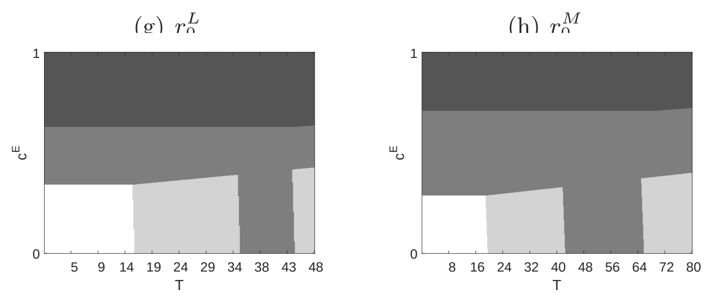
(I) Low default risk (θ^L) and Low financial cost (l^L)



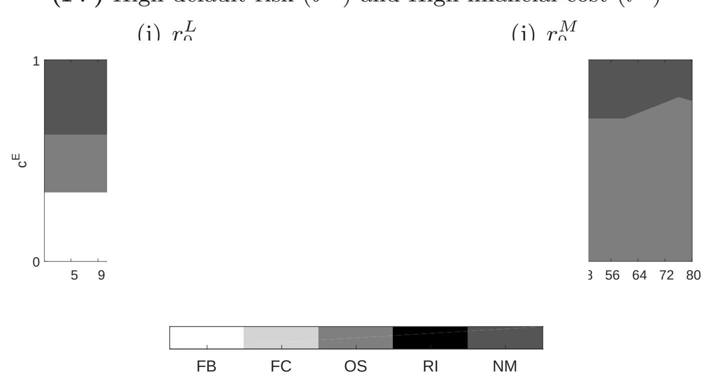
(II) Low default risk (θ^L) and High financial cost (l^H)



(III) High default risk (θ^H) and Low financial cost (l^L)



(IV) High default risk (θ^H) and High financial cost (l^H)



E.2. Non-cancelable contracts

To identify the optimal non-cancelable contracts, note that Lemmas C.2 and C.3 characterize the optimal contract under each shipping threshold $i^{NC} = 1, \ldots N$. That is, among those non-cancelable contracts that induce the supplier to ship only at signal $i < i^{NC}$, we can write the optimal one in closed form. As such, we can obtain the optimal contract by simply comparing these N candidates.

Using the same format as in Figure 2, we summarize the optimal non-cancelable contract under different parameters (T, c^E, r_0, l) in Figure 7. The regions corresponding to the greyscale are presented in the bar below the figures. First, note that all figures exhibit similar patterns as characterized in Proposition 1 and illustrated in Figure 2. Specifically, the optimal non-cancelable contract can only achieve the first-best outcome when both c^E and T are small. As either parameter increases, the optimal contract results in either financing costs or over-shipping until finally, the optimal contract no longer induces the insurer to exert monitoring effort.

By comparing the figures within one row, we can identify the impact of the attractiveness of the supplier's outside option. For example, a comparison between Figures 7(a) – 7(c) (or any set of figures in the same row) reveals that a more attractive outside option in general, leads to a smaller first-best region (FB) and more over-shipping (OS). This is consistent with our theory that the main shortcoming of the non-cancelable contract is that the deductible alone often fails to deter the supplier from shipping when the buyer is risky. This over-shipping tendency becomes more prevalent when the supplier's outside option is attractive.

Similarly, we can identify the impact of the supplier's financing cost by comparing Figures in (I) with their counterparts in (II) and (III) with (IV). The most notable difference is that when T is large, the FC region gives way to OS since maintaining the efficient shipping decision becomes more costly when l is high. Similarly, when both c^E and T are high, no monitoring (NM) is more likely to be the optimal contract.

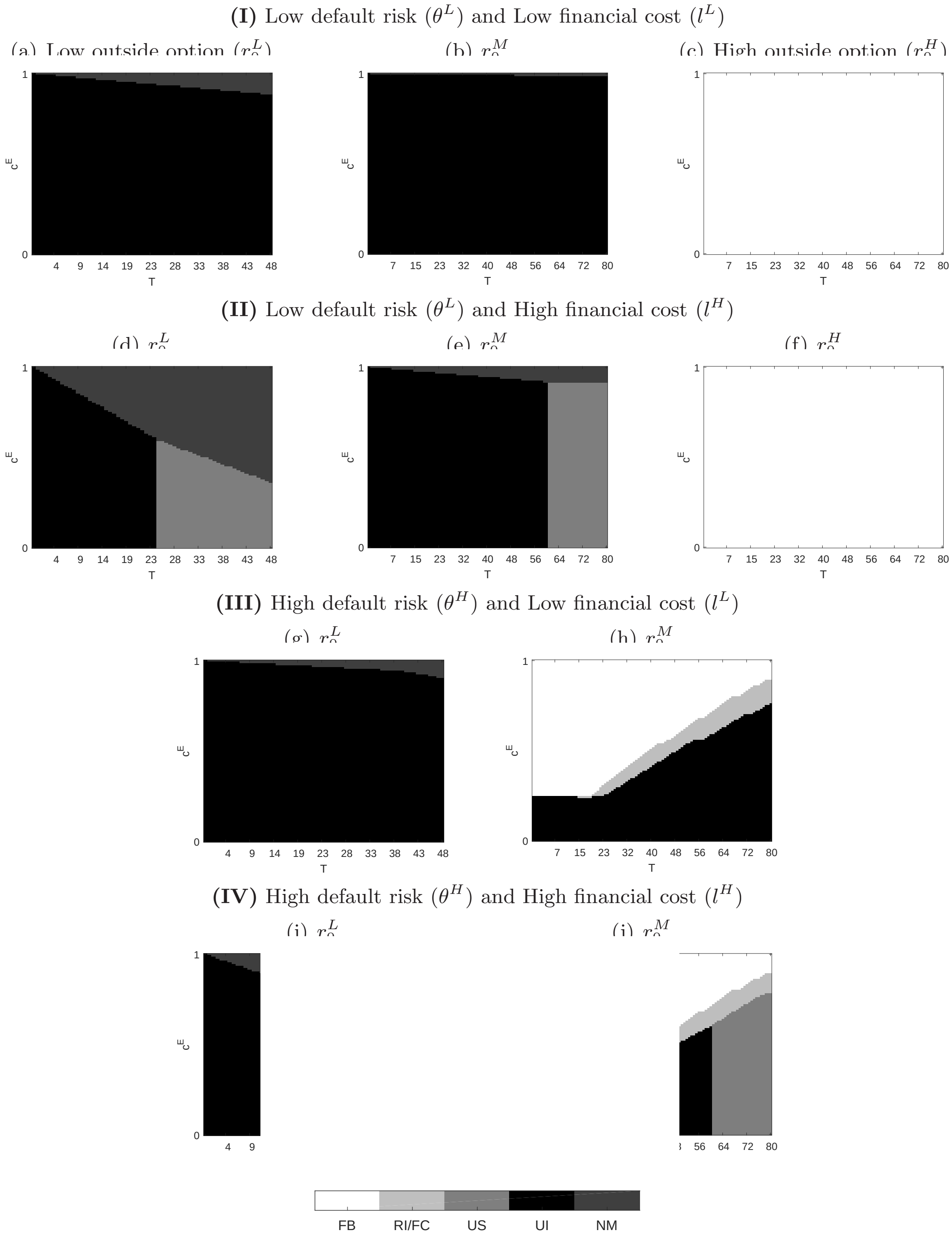
Finally, the impact of default risk can be identified by comparing Figures in (I) and their counterparts in (III) and (II) with (IV). We note that high default risk in general makes the contract that induces over-shipping (OS) less attractive relative to those that result in financing costs. This is because the higher probabilities θ_i associated with the riskier signals cause over-shipping to be increasingly inefficient operationally.

E.3. Cancelable contracts

When solving for the optimal cancelable contract, as in the main body of the paper, we consider only the set of feasible contracts under which the insurer exerts effort. Using the math program laid out in Lemma C.4, we can identify the optimal contract under each set of shipping and cancelation thresholds (i^C, i^{CC}, i^{CN}). We thus iterate across the feasible combinations of the three thresholds and obtain the optimal contract by comparing payoffs.

Using the structural results in Section 6, we limit the thresholds over which we iterate in the following ways. For the insurer's cancelation, we consider only $i^C \in \{2, \ldots, N-1\}$ in order to omit the thresholds where the insurer either never cancels or always cancels (since the insurer would not exert effort under these contracts). We restrict i^{CC} to $\{2, \ldots, i^{FB}\}$, where i^{FB} is the first-best shipping threshold, by the definition of β^{CC}. Finally, based on Lemma 5, we limit i^{CN} to $\{\max(i^C, i^{CC}), \ldots, N\}$.

Figure 8 Numerical results for the optimal cancelable contract with $N = 10$ signals and financing cost l under various outside options (r_0) and expected default risk (θ^i).



To solve for the optimal contract more efficiently, we manage to reformulate (118) –(126) as a linear program, as detailed in Section E.5. Not surprisingly, this LP reformulation has greatly shortened the time required to solve for the optimal cancelable contracts.

Following the styling of Figure 3, we illustrate the optimal cancelable contract across all cases in Figure

8. The regions corresponding to the greyscale is given in the bar below the figures.

In general, our numerical results confirm our main finding (Proposition 2) that when facing attractive outside options, as shown in Figures 8(c) and 8(f), or when the insurer's monitoring cost is high, the cancelable contract can achieve first-best. However, when the supplier's outside option becomes less attractive, the insurer over-cancels relative to the first-best. As a result, the supplier is either shipping uninsured, or under-ships (Proposition 3). Combining these two aspects, Figure 8(h) and 8(j) share several similarities with Figure 3.

Regarding the impact of other parameters, as the supplier's financing cost increases (l^H), we observe, by comparing figures within the same column, that the supplier becomes more conservative in her shipping decision (ships over fewer signal classes) when T is large. With higher financing costs and thus more conservative shipping, the monitoring role of insurance is less valuable, so that the insurer exerts effort over a smaller range of c^E (larger NM region).

By comparing Figures in (I) with those in (III), and (II) with (IV), we observe that the higher expected default probability (θ^H) actually reduces the efficiency losses of the optimal contract relative to first best by making it optimal to cancel more aggressively. Thus, the insurer no longer over-cancels so that his cancelation decision can achieve first-best (under r_0^M), and the supplier can subsequently ship with coverage. This is consistent with our structural results in Lemma C.6, which are shown in Figures 5(c)–5(f).

E.4. Contract comparison

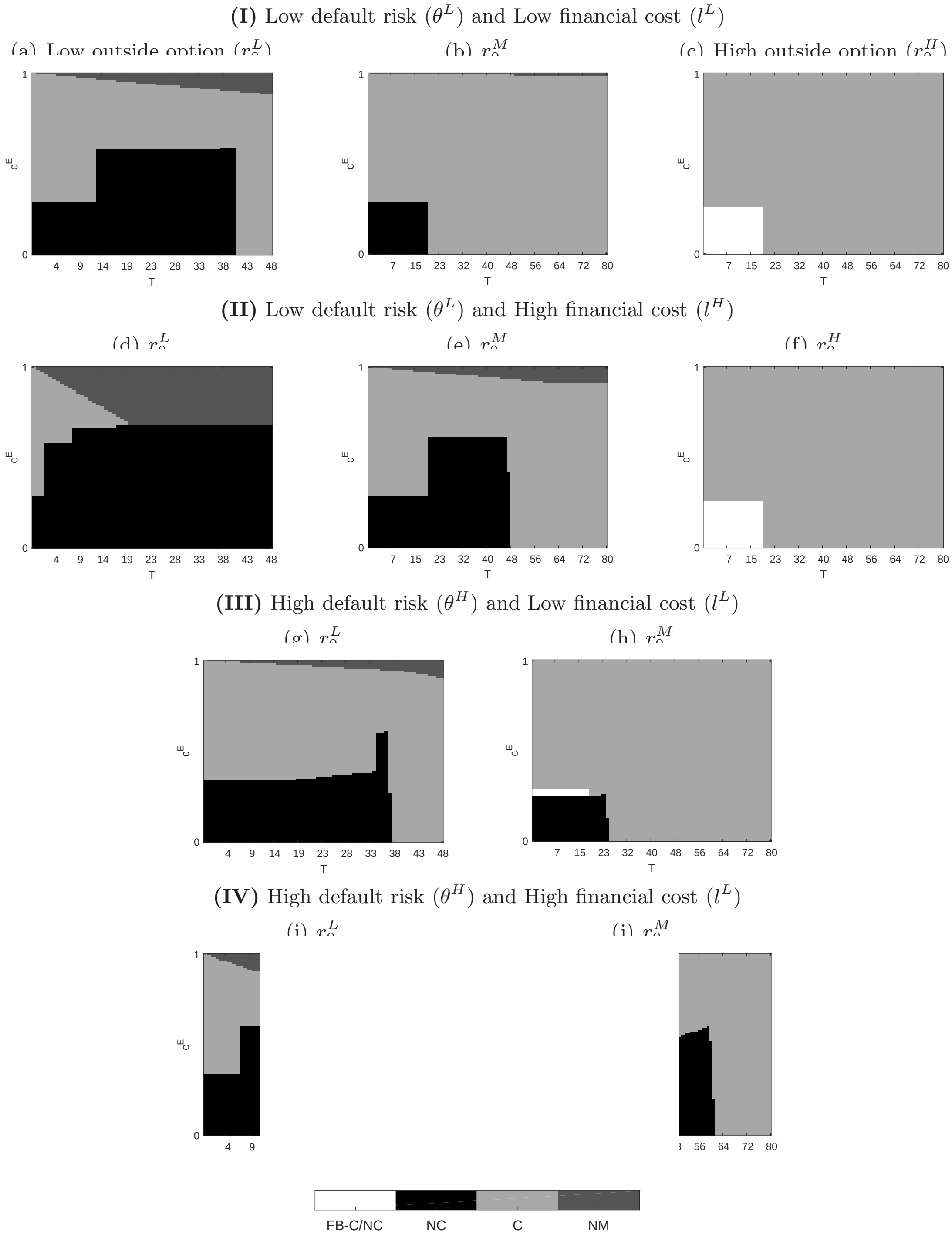
Comparison of the optimal cancelable and non-cancelable contracts across (T, c^E, r_0, l) is presented in Figure 9. As shown, the optimal non-cancelable contract is often the dominating one when c^E is small (the black region). This is consistent with Corollary 2. Non-cancelable contracts, however, become less attractive as the supplier's outside option improves. Note that in Figure 9(c) and 9(f), as discussed above, as the optimal cancelable contract always achieves first-best, it is never strictly dominated by any non-cancelable one. Indeed, the small white region in these two figures indicate that in this region, both cancelable and non-cancelable contracts can achieve first-best.

As the supplier's financing cost increases, by comparing figures in the same column, we observe that the non-cancelable contract becomes more attractive over a greater range of c^E and T. This is consistent with our earlier results that the smoothing role of TCI becomes more important with high financing costs so that guaranteed coverage (non-cancelable) is preferred.

Finally, as the buyer's expected default risk increases (comparing (I) with (III) and (II) with (IV)), the monitoring role becomes more important so that the cancelable contract, which more readily induces monitoring effort, becomes more attractive.

In summary, through an extensive numerical study, we have confirmed that 1) the cancelable contract can better induce actions that fulfill the dual roles of TCI when the supplier's outside option is attractive or when the cost of effort is high; and 2) the non-cancelable contract often lead to over-shipping. However, it can dominate the cancelable contract when the outside option is unattractive or cost of effort is low.

Figure 9 Comparison of the cancelable and non-cancelable contracts with $N = 10$ signals, financing costs (l^L, l^H), outside options (r_0^L, r_0^M, r_0^H), and expected default risk $(\bar{\beta}^L, \bar{\beta}^H)$.



E.5. Linear program formulation for the optimal cancelable contract

In order to solve (118)–(126) efficiently, we reformulate the problem in Lemma C.4 as a linear program by introducing an additional decision variable F for the supplier's cash shortfall. The corresponding linear program, with p^C, δ^C, f^C, and F as decision variables, is presented in (275) – (286).

$$\max_{p^C,\delta^C\in[0,r],f^C\le p^C,F\ge 0} r_0 - p^C + \sum_{i<i^C}\theta_i[(r-r_0)-\beta_i(\delta^C+F)] + \sum_{i=i^C}^{i^{CC}}\theta_i[(r-r_0)-\beta_i(r+l(T-f^C+p^C)))] + \sum_{i=i^C}^{i^{CN}}\theta_i f^C. \tag{275}$$

$$r-r_0 \ge \bar{\beta}(\delta^C+lF) \tag{276}$$

$$\bar{\beta}(r-\delta^C) \ge c^E + \sum_{i<i^C}\theta_i\beta_i(r-\delta^C) + \sum_{i\in[i^C,i^{CN}]}\theta_i f^C \tag{277}$$

$$f^C \ge c^E + \sum_{i<i^C}\theta_i\beta_i(r-\delta^C) + \sum_{i\in[i^C,i^{CN}]}\theta_i f^C \tag{278}$$

$$p^C \ge c^E + \sum_{i<i^C}\theta_i\beta_i(r-\delta^C) + \sum_{i\in[i^C,i^{CN}]}\theta_i f^C \tag{279}$$

$$f^C < \beta_{i^C}(r-\delta^C) \tag{280}$$

$$f^C \ge \beta_{i^C-1}(r-\delta^C) \tag{281}$$

$$(1-\beta_{i^{CC}-1})r - r_0 > \beta_{i^{CC}-1}l(T-f^C+p^C) \tag{282}$$

$$(1-\beta_{i^{CC}})r - r_0 \le \beta_{i^{CC}}l(T-f^C+p^C) \tag{283}$$

$$r-r_0 > \beta_{i^{CN}-1}(\delta^C+lF) \tag{284}$$

$$r-r_0 \le \beta_{i^{CN}}(\delta^C+lF) \tag{285}$$

$$F \ge T-r+p^C+\delta^C \tag{286}$$

Appendix F: The impact of the insurer's financing cost

In the paper, in order to focus on both parties' moral hazards, we ignore other possible financial frictions on the insurer's side. In this appendix, we extend our model by incorporating the insurer's financing cost, as in Dong and Tomlin (2012). Specifically, we assume that when processing a claim of amount x, the insurer incurs a cost proportional to the size of the claim.[22] We denote this cost proportion by l_I. Thus, the insurer incurs a total financing cost of $l_I x$. As the insurer is often financially stronger than the insured party, we assume that l_I is much smaller l, the supplier's unit financing cost.

In this section, we begin by establishing how the insurer's financing cost influences the first-best benchmark and the potential value of TCI. We then present structural results and the optimization problems corresponding to the non-cancelable and cancelable contracts, respectively. Finally, through numerical analysis, we verify that the main insights of the paper are robust in the presence of the insurer's financing cost.

F.1. The potential value of TCI in the presence of the insurer's financing cost

As in Section 4, we first establish the first-best benchmark in the presence of the insurer's financing cost.

Lemma F.1 *Let $\beta_l^{FB}(T) = \frac{r-r_0}{r+l_I T}$, and $\bar{C}_l^E(T) = \max_i r\sum_{j=i}^N \theta_j\,[\beta_j - \beta_l^{FB}(T)]$, and $\Pi_l^{NE} = (1-\bar{\beta})r - \bar{\beta} l_I T$. When $l_I \leq \frac{(1-\bar{\beta})r-r_0}{(2r_0-r)\bar{\beta}}$, the first-best benchmark in the presence of the insurer's financing cost is as follows.*

1. *When $c^E \leq \bar{C}_l^E(T)$, the insurer exerts effort and the supplier ships if and only if the observed signal i satisfies $\beta_i \leq \beta_l^{FB}(T)$. The corresponding payoff is $\Pi_l^E := \Pi^{NE} + \bar{C}_l^E(T) - c^E$.*
2. *When $c^E > \bar{C}_l^E(T)$, the insurer does not exert effort and the supplier always ships the order. The corresponding payoff is Π_l^{NE}.*

As shown, when the insurer's financing cost is reasonably low, the structure of the first-best benchmark is similar to that in Lemma 1.[23] However, we make two notable observations. First, in the presence of the insurer's financing cost, the supplier's efficient shipping decision becomes more conservative as T increases, i.e., $\beta_l^{FB}(T)$ is decreasing in T. This is because the insurer's financing cost makes shipping (under coverage) relatively less attractive. Second, and more interestingly, as T increases, the insurer may exert effort over a larger range of c^E. This is captured by the fact that the cost of effort threshold $\bar{C}_l^E(T)$ is increasing in T. This is consistent with our observations in Lemma 1: when β^{FB} decreases, monitoring becomes more valuable. In the presence of the insurer's financing cost, monitoring becomes more valuable since T lowers the payoff from shipping to a risky buyer.

Using this result, we can quantify the potential value of TCI by comparing the above first-best benchmark with the no-insurance benchmark (Lemma 2), which is independent of the insurer's financing cost. Therefore, the dual values of TCI are qualitatively unchanged.

[22] Numerically, we have verified that adding a fixed component to the financing cost does not change the main insights of our paper. We omit this detail for expositional brevity.

[23] When $l_I > \frac{(1-\bar{\beta})r-r_0}{(2r_0-r)\beta}$, for sufficiently large c^E (hence no updated information) and T, the supplier may not ship at all under the prior expected default probability. This complicates the exposition without adding additional insight.

F.2. The optimal non-cancelable contract in the presence of the insurer's financing cost

Intuitively, the insurer's financing cost influences his expected claim payment, and hence has an impact on the formulation of the optimization problem that determines the optimal non-cancelable contract. We examine the impact as follows.

First, by examining the structural results in Section 5, we note that the supplier's shipping threshold under a given contract, β^{NC}, as defined in (1), is independent of the insurer's financing cost. However, the insurer's IC and IR constraints are all influenced by his financing cost. Specifically, (NC-IC1), (NC-IC2), and (NC-IR) in Lemma 3 must be modified as follows:

$$\beta^{NC} \geq \bar{\beta}; \tag{NC.L-IC1}$$

$$(1+l_I)\bar{\beta}(r-\delta^{NC}) \geq c^E + (1+l_I)(r-\delta^{NC}) \sum_{i \leq i^{NC}} \theta_i \beta_i; \tag{NC.L-IC2}$$

$$p^{NC} \geq c^E + (1+l_I)(r-\delta^{NC}) \sum_{i \leq i^{NC}} \theta_i \beta_i; \tag{NC.L-IR}$$

where $i^{NC} = \max\{i : \beta_i \leq \beta^{NC}\}$. As shown, the expected claim-related costs to the insurer all include the financing cost term l_I. Following the same steps as in the proof of Lemma 3, we can show that when (NC.L-IC1), (NC.L-IC2), and (NC.L-IR) are satisfied, the insurer has the incentive to exert effort under a given contract (p^{NC}, δ^{NC}).

Next, we discuss the impact on the optimal contract. Similar to Section 5, we consider the optimal contract that does or does not induce the insurer's effort separately. Below, we characterize the optimal non-cancelable contract under which the insurer does not exert effort.

Lemma F.2 *In the presence of the insurer's financing cost, among all insurance contracts (p^{NC}, δ^{NC}) that do not induce the insurer to exert effort, the one with $p^{NC} = (1+l_I)\bar{\beta}T$ and $\delta^{NC} = r - T$ is (weakly) dominating. Under this contract, the supplier always ships the order and her expected payoff is Π_l^{NE}.*

As shown, even in the presence of the insurer's financing cost, the optimal non-cancelable contract that does not induce the insurer to exert effort can still fully recover the smoothing value of TCI.

In terms of the optimal non-cancelable contract that induces the insurer's effort, we note that under a given contract (p^{NC}, δ^{NC}), the supplier's payoff function, (NC-OBJ), is not influenced by the insurer's financing cost. Therefore, we can find the optimal non-cancelable contract by solving (NC-OBJ) subject to (NC.L-IC1), (NC.L-IC2), and (NC.L-IR). We present the results numerically in a later subsection.

F.3. The optimal cancelable contract in the presence of the insurer's financing cost

Analogous to the non-cancelable contract, under a given contract, the supplier's shipping thresholds, either with (β^{CN}) or without (β^{CC}) coverage, are independent of l_I. However, the insurer's cancelation threshold, β^C, is influenced by l_I. To see that, note that β^C is determined by comparing the insurer's cost of claim payment $(1+l_I)\beta(r-\delta^C)$, which depends on l_I, and the refund f^C, which is independent of l_I. Therefore, following the same logic as in Section 6, the insurer cancels coverage if and only if $\beta_i \in [\beta_l^C, \beta^{CN})$, where

$$\beta_l^C := \frac{f^C}{(1+l_I)(r-\delta^C)}. \tag{287}$$

As shown, all else equal, the insurer's financing cost induces him to adopt a more aggressive cancelation policy, i.e., he may cancel the supplier's coverage under a larger range of signals. As such, the insurer's financing cost may further aggravate the problem of over-cancelation as identified in the main body of the paper.

Next, we consider the insurer's incentive to exert effort under a contract (p^C, δ^C, f^C) (corresponding to Lemma 6 in the paper). Following the same proof, we can show that under a contract (p^C, δ^C, f^C), the insurer has incentive to exert effort if and only if the following conditions are satisfied:

$$\beta^{CN} \geq \bar{\beta}; \tag{C.L-IC1}$$

$$(1+l_I)\bar{\beta}(r-\delta^C) \geq c^E + (1+l_I)\sum_{i<i_l^C}\theta_i\beta_i(r-\delta^C) + \sum_{i\in[i_l^C, i^{CN}]}\theta_i f^C; \tag{C.L-IC2}$$

$$f^C \geq c^E + (1+l_I)\sum_{i<i_l^C}\theta_i\beta_i(r-\delta^C) + \sum_{i\in[i_l^C, i^{CN}]}\theta_i f^C; \tag{C.L-IC3}$$

$$p^C \geq c^E + (1+l_I)\sum_{i<i_l^C}\theta_i\beta_i(r-\delta^C) + \sum_{i\in[i_l^C, i^{CN}]}\theta_i f^C; \tag{C.L-IR}$$

where $i_l^C = \min\{i : \beta_i > \beta_l^C\}$ and $i^{CN} = \max\{i : \beta_i \leq \beta^{CN}\}$. As shown, the insurer's financing cost influences the insurer's expected cost through his IR and IC constraints, as well as through the cancelation threshold, i_l^C.

Similarly, the supplier's objective function under the contract is identical to (C-OBJ), except that i^C is replaced by i_l^C as defined above. Therefore, the optimal cancelable contract can be characterized by solving:

$$\begin{aligned}\max_{p^C,\delta^C\in[0,r], f^C\leq p^C} \; & \sum_{i<i_l^C}\theta_i[r-\beta_i(\delta^C+L(r-p^C-\delta^C))] + \sum_{i=i_l^C}^{i^{CC}}\theta_i[(1-\beta_i)r-\beta_i L(f^C-p^C)] \\ & + \sum_{i\geq\max(i_l^C, i^{CC}+1)}\theta_i r_0 + \sum_{i=i_l^C}^{i^{CN}}\theta_i f^C - p^C.\end{aligned} \tag{C.L-OBJ}$$

subject to (C.L-IC1)–(C.L-IR). We present the characteristics of the optimal contract numerically in the next section.

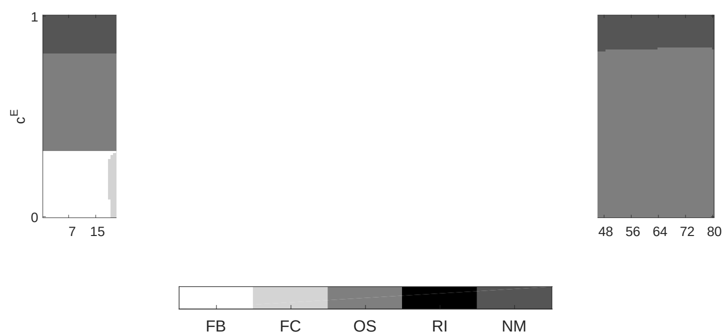
F.4. Numerical results and contract comparison

To examine the impact of the insurer's financing cost on the cancelable and non-cancelable contracts and their relative attractiveness, we continue using the parameters from Appendix E. In particular, we consider the scenario with $N = 10$ signal classes where the expected default risk is high ($\bar{\beta}^H$). We fix the supplier's financing cost at $l = 100\%$ and outside option at $r_0^M = (1-8\%)r$. We then numerically analyze the optimal contract in two cases: when the insurer's financing cost is $l_I \in \{1\%, 5\%\}$.

The optimal non-cancelable contract in the presence of the insurer's financing cost is presented in Figure 10. First, by comparing the two figures to each other and to Figure 7(j), we observe that the insurer's financing cost does not have a qualitative impact on the shape of the different regions; however, it does change their relative sizes. For example, we note that in the presence of financing costs, the insurer exerts effort for a larger range of c^E and T, which is consistent with our analysis above that monitoring becomes more valuable.

Figure 10 **The impact of the insurer's financing cost (l_I) on the optimal non-cancelable contracts**

(a) Low financing cost ($l_I =$ 1%) (b) High financing cost ($l_I =$ 5%)

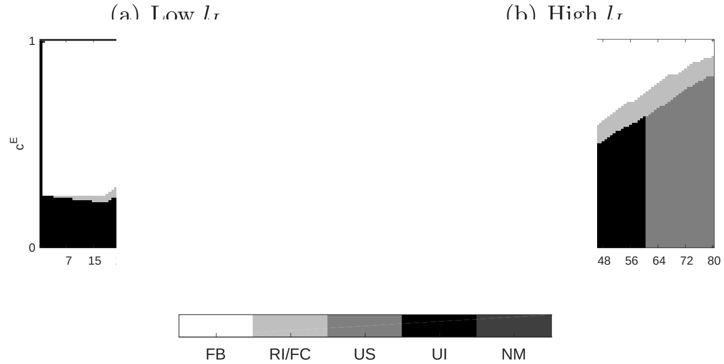


Notes. Number of signal classes $N = 10$. The supplier's financing cost is $l = 1$, outside option is medium ($r_0^M = 92$) and the expected default risk follows the H scenario in Appendix E, i.e, $\bar{\beta}^H = 5.3\%$.

The impact of the insurer's financing cost on the optimal cancelable contract is shown in Figure 11. Likewise, incorporating the insurer's financing cost does not alter the basic patterns/shape of the regions. In addition, we observe that when T is very small, the presence of the insurer's financing cost could cause the insurer to over-cancel (the same region corresponds to first-best at $l_I = 0$). As the financial constraint is not a major concern for the supplier (small T), creating a thin slice of UI (under-insured) Region. The reason lies exactly in our earlier discussion about the impact of l_I on the insurer's cancelation decision. Recall that in the presence of l_I, the insurer's expect claim-related cost, $\beta_i(1+l_I)(r-\delta^C)$ increases in l_I, while his cost of cancelation, f^C, is independent of l_I. As such, a greater l_I leads to more severe over-cancelation.

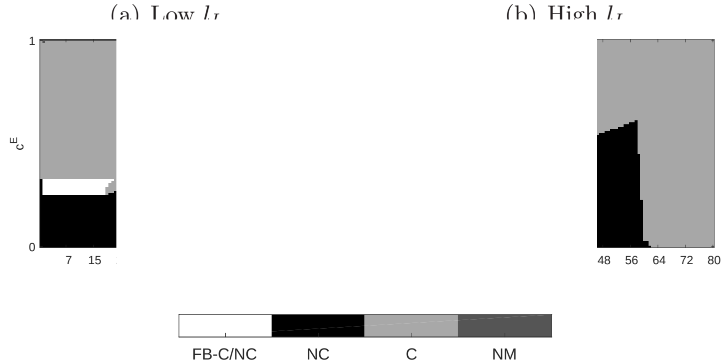
Figure 11 **The impact of the insurer's financing cost (l_I) on the optimal cancelable contracts**

(a) Low l_I (b) High l_I



Comparing the two contracts in Figure 12, we find that our insights from the main body of the paper and from the numerical studies in the previous section continue to hold even with the addition of the insurer's financing cost. That is, the non-cancelable contract remains dominant when c^E is low and can actually achieve the first-best outcome. As c^E and T increase, the cancelable contract is able to fulfill the dual roles of TCI.

Figure 12 The impact of the insurer's financing cost (l_I) on contract comparison



F.5. Proofs

Proof of Lemma F.1. Regardless of the insurer's effort, we note that because it is costly for the insurer to provide coverage and the supplier does not incur any cost beyond her cashflow target T, the insurer should only provide coverage up to T. The cost of providing such coverage is $l_I T$. Therefore, the supplier ships if and only if the buyer's default risk β satisfies:

$$(1-\beta)r - \beta l_I T > r_0. \tag{288}$$

or equivalently,

$$\beta < \frac{r-r_0}{r+l_I T} =: \beta_l^{FB}(T). \tag{289}$$

Note that $\beta_I^{FB}(T)$ is decreasing in T.

Next, consider the two cases depending on whether the insurer exerts monitoring effort or not.

1. Without effort, if the supplier ships under coverage, the payoff in the centralized system, including the insurer's financing cost, is:

$$\Pi_l^{NE} = \sum_i \theta_i \left[(1-\beta_i)r - \beta_i l_I T\right] = (1-\bar{\beta})r - \bar{\beta} l_I T. \tag{290}$$

If the supplier does not ship, she receives r_0. By comparing these two scenarios, we find:

(a) if $\Pi_l^{NE} \geq r_0$, i.e.,

$$T \leq \frac{(1-\bar{\beta})r - r_0}{l_I \bar{\beta}}, \tag{291}$$

the supplier ships the order.

(b) if $T > \frac{(1-\bar{\beta})r-r_0}{l_I\bar{\beta}}$, the supplier does not ship the order.

Under the condition that $l_I \leq \frac{(1-\bar{\beta})r-r_0}{(2r_0-r)\bar{\beta}}$, the supplier always ships the order when the insurer does not exert effort.

2. if the insurer exerts effort and hence obtains updated information, the supplier ships the order if and only if the received signal i satisfies $\beta_i \leq \beta_l^{FB}(T)$. Similar to the proof of Lemma 1, we define $i_l^{FB} = \min\{i : \beta_i > \beta_l^{FB}\}$. Therefore,

$$\Pi_l^E = \sum_{i<i_l^{FB}} \theta_i[(1-\beta_i)r - \beta_i l_I T] + \sum_{i \geq i_l^{FB}} \theta_i r_0 - c^E. \tag{292}$$

$$= \Pi_l^{NE} + r \sum_{i \geq i_l^{FB}} \theta_i \left[\beta_i - \beta_l^{FB}(T) \right] - c^E \tag{293}$$

Similarly to the proof of Lemma 1, we define $\bar{C}_l^E(T)$ as follows:

$$\bar{C}_l^E(T) := \max_i r \sum_{j=i}^{N} \theta_j \left[\beta_j - \beta_l^{FB}(T) \right]. \tag{294}$$

Note that as $\beta_l^{FB}(T)$ decreases in T, $\bar{C}_l^E(T)$ increases in T.

By comparing the centralized system's payoff with and without effort, we have the following two scenarios.

1. for $c^E \leq \bar{C}_l^E(T)$, $\Pi_l^E \geq \Pi_l^{NE}$, it is optimal for the insurer to exert effort, and the supplier ships if and only if $\beta_i \leq \beta_l^{FB}$.
2. for $c^E > \bar{C}_l^E(T)$, $\Pi_l^E < \Pi_l^{NE}$, it is optimal for the insurer to not exert effort, and the supplier always ships. □

Proof of Lemma F.2. The proof is similar to that of Lemma 4. We first construct the optimal contract (p^{NC}, δ^{NC}). Note that when $\delta^{NC} > r - T$, the supplier incurs financing cost, which is higher than the insurer's. However, when $\delta^{NC} < r - T$, the insurer incurs financing cost, while the supplier does not benefit from the lower deductible. Thus, the optimal contract should yield $\delta^{NC} = r - T$. With regards to the premium, as the insurer does not exert effort, p^{NC} should equal the insurer's total expected cost of claim. As the supplier always ships the order, we have:

$$p^{NC} = \sum_i \theta_i \beta_i (1 + l_I)(r - \delta^{NC}) = (1 + l_I)\bar{\beta} T, \tag{295}$$

and thus the supplier's payoff is:

$$\Pi = \sum_i \theta_i [(1 - \beta_i) r + \beta_i T] - p^{NC} = (1 - \bar{\beta}) r - l_I \bar{\beta} T = \Pi_l^{NE}. \tag{296}$$

Because Π_l^{NE} is the highest payoff the supplier can receive when the insurer does not exert effort, the above contract is the (weakly) dominating contract. □

Appendix G: The insurer's incentive to voluntarily disclose information

In the main body of the paper, in order to focus on the insurer's moral hazard associated with exerting monitoring effort, we assume that once the insurer has exerted effort and obtained the updated information, he will always share this information with the supplier. In this section, we relax this assumption and examine the case when the insurer has the discretion to decide whether to disclose the information he has obtained. In what follows, we show that under the optimal contract that we have identified in the paper, the insurer indeed has the incentive to disclose all the information he has obtained.

Based on our understanding of the TCI industry, and our communication with TCI practitioners, we adopt the *disclosure of certifiable information* framework, which is widely used in the economics literature (e.g., Okuno-Fujiwara et al. 1990, Shavell 1994, and Bolton and Dewatripont 2005, Chapter 5). Under this framework, because all information is certifiable, if the insurer decides to disclose his private information, he must reveal the information truthfully. He can, however, choose to *not* disclose the information, because the state of no information is not certifiable. In other words, the insurer only has the discretion to withhold information, but not to manipulate the content of the information. This is consistent with our understanding of TCI practice. For example, while the insurer may not present the buyer's latest financial statement, which includes some worrying signs regarding the buyer's financial situation, to the supplier, he cannot fabricate such a financial statement himself, as the supplier can verify this piece of information later independently.

Adopting this framework to the TCI setting, we assume that all information is certifiable, except for the positive state $i=1$, which corresponds to the case where no risk-aggravating event is discovered. Thus, if the insurer does not disclose a piece of negative information, then from the supplier's perspective, she observes no updated information, which is indistinguishable from the positive signal $i=1$. In equilibrium, if the supplier anticipates that the insurer will withhold information upon receiving signal $i \in \mathcal{I}$, where $\mathcal{I} \subset \{2, \ldots, N\}$, she will update her posterior belief once she observes no updated information as follows:

$$\beta^{EP} = \frac{\theta_1 \beta_1 + \sum_{i \in \mathcal{I}} \theta_i \beta_i}{\theta_1 + \sum_{i \in \mathcal{I}} \theta_i}. \tag{297}$$

We refer to the set $\mathcal{I}$ as the insurer's information withholding policy. Next, we establish the necessary condition for the insurer's specific information withholding policy.

Lemma G.1 *Under any non-cancelable contract that induces the insurer's effort, the insurer withholds information of type $i \in \mathcal{I}$ only if the supplier does not ship when she receives no information update, or equivalently,*

$$\beta^{EP}(\mathcal{I}) > \beta^{NC}. \tag{298}$$

Under any cancelable contract that induces the insurer's effort, the insurer withholds information of type $i \in \mathcal{I}$ only if the supplier does not ship under coverage when she receives no information update, or equivalently,

$$\beta^{EP}(\mathcal{I}) > \beta^{CN}. \tag{299}$$

Lemma G.1 reveals that the only incentive for the insurer to withhold information is to prevent the supplier from shipping. Intuitively, if the insurer can, by withholding certain negative information, distort the supplier's posterior belief β^{EP} such that she chooses not ship, then the insurer can remove his liability for the buyer's default, which lowers his expected cost. Conversely, if the supplier ships even under the posterior belief, then the insurer is weakly better off disclosing the negative information so that the supplier may at least choose not to ship upon receiving certain signal i (e.g., the most negative one).

In addition, we note that under cancelable contracts, the insurer only has the incentive to withhold information of type i if he does not cancel coverage at i. The reason is also intuitive: if the insurer cancels coverage, he has already removed his liability. Thus, he has no incentive to withhold information.

Proposition G.1 *Under both the optimal non-cancelable and the optimal cancelable contract that induces the insurer to exert effort, i.e., the contracts in Propositions 3 and C.1, the insurer voluntarily discloses all updated information.*

Proposition G.1 confirms that under the optimal contracts that we have identified in the paper, the insurer always has the incentive to disclose all information. Intuitively, this is because, from the insurer's perspective, he prefers the supplier to not ship. To discourage shipping, the insurer only has the incentive to distort information such that the supplier believes the buyer's default risk is significant. Withholding information, however, is not a very efficient way to achieve this goal, as withholding information means that the supplier will form a posterior belief that merges the safest state ($i = 1$) with some bad states ($i \in \mathcal{I}$). As the safest state is also likely to be the most common state (i.e., large θ_1), the posterior belief is unlikely to be large. On the other hand, under the optimal contracts identified in the paper, the default risk threshold at which the supplier stops shipping (under coverage) is in general reasonably large, as setting a small β^{NC} (or β^{CN}) is often associated with a sufficiently large deductible, which in turn leads to a high financing cost. As such, we find that even if the insurer withholds all of the most negative signals, the posterior belief is still not high enough to prevent the supplier from shipping. Consequently, the insurer often prefers to disclose all information. When he does so, the supplier at least stops shipping when she receives the most negative signals.

Having shown that the insurer has the incentive to disclose information under the $N = 3$ case, we further verify the insurer's incentive numerically under the parameter we use in Appendix E. By considering different information withholding policies, i.e., $\mathcal{I}$, the insurer may adopt, and compare the resulting β^{EP} with the β^{NC} and β^{CN} as identified in Appendix E, we can use Lemma G.1 to exclude the possibility that the insurer strategically withholds information.

Combining both the analytical and numerical results, we conclude that in our model, even with the option to withhold information at his discretion, it is always in the insurer's best interest to fully disclose his information.

G.1. Proofs

Proof of Lemma G.1. We focus on the non-cancelable contracts. The corresponding result under cancelable contracts follows the exact same logic.

We prove the result by contradiction. Assume that the insurer withholds information when the signal belongs to group $i \in \mathcal{I}$. Anticipating this, the supplier forms posterior belief $\beta^{EP}(\mathcal{I})$ as follows:

$$\beta^{EP}(\mathcal{I}) = \frac{\theta_1\beta_1 + \sum_{i\in\mathcal{I}}\theta_i\beta_i}{\theta_1 + \sum_{i\in\mathcal{I}}\theta_i}. \tag{300}$$

Assume that $\beta^{EP}(\mathcal{I}) < \beta^{NC}$. We will show that this information withholding policy $\mathcal{I}$ is weakly dominated by some other policies.

To see that, let i^{max} be the largest element in $\mathcal{I}$. For example, if $\mathcal{I} = \{4, 5, 6\}$, then $i^{max} = 6$. Now consider two scenarios.

1. if $\beta_{i^{max}} > \beta^{NC}$, i.e., if the insurer discloses i^{max}, then the supplier does not ship the order. Now consider the case where the insurer only withholds information for $i \in \mathcal{I}/\ i^{\max} := \mathcal{I}'$. Anticipating this information withholding policy, the supplier's posterior belief becomes:
$$\beta^{EP}(\mathcal{I}') = \frac{\theta_1\beta_1 + \sum_{i\in\mathcal{I}'}\theta_i\beta_i}{\theta_1 + \sum_{i\in\mathcal{I}'}\theta_i} < \beta^{EP}(\mathcal{I}) < \beta^{NC}. \tag{301}$$
Therefore, the supplier still ships when receiving no information. However, because she does not ship at signal i^{max}, if the insurer truthfully discloses it to her, the insurer's expected claim payment is strictly lower under $\mathcal{I}'$ than under $\mathcal{I}$.
2. if $\beta_{i^{max}} < \beta^{NC}$, i.e., if the insurer discloses i^{max}, the supplier does ship the order. Then the insurer's expected claim payment under $\mathcal{I}$ is exactly the same as the one where he discloses all information.

Combining the two scenarios, we can see that any withholding policy $\mathcal{I}$ under which $\beta^{EP}(\mathcal{I}) < \beta^{NC}$ cannot be optimal. □

Proof of Proposition G.1. We consider the optimal non-cancelable and cancelable contracts separately.

First, for the non-cancelable contract, based on the proof of Proposition C.1, as well as Lemma C.2, we know that the optimal non-cancelable contract which induces the insurer to exert effort must be one of the following three:

1. $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$: under this contract, the corresponding $\beta^{NC} = \beta_3$.
2. $(p^{NC}_{IR,2}, \delta^{NC}_{IR,2})$: under this contract, the corresponding $\beta^{NC} = \beta_2$. According to Lemma C.2, this contract is only feasible (in the sense that it induces the insurer to exert effort) when $\beta_2 > \bar{\beta}$.
3. $(p^{NC}_{IC,2}, \delta^{NC}_{IC,2})$: under this contract, the corresponding $\beta^{NC} = \beta_2$. Similar to the above case, this contract is only feasible (in the sense that it induces the insurer's effort) when $\beta_2 > \bar{\beta}$.

Next, consider all of the insurer's possible information withholding policies.

1. if the insurer withholds information when $i = 2$, i.e., $\mathcal{I} = \{2\}$, then the supplier's posterior belief is given by:
$$\beta^{EP}(\mathcal{I}) = \frac{\theta_1\beta_1 + \theta_2\beta_2}{\theta_1 + \theta_2} < \bar{\beta}. \tag{302}$$
Note that all three possible optimal contracts satisfy $\beta^{NC} > \beta_2$. Therefore, $\beta^{EP}(\mathcal{I}) < \beta^{NC}$. According to Lemma G.1, this information withholding policy cannot be optimal.

2. if the insurer withholds information when $i = 3$, i.e., $\mathcal{I} = \{3\}$,

$$\beta^{EP}(\mathcal{I}) = \frac{\theta_1\beta_1 + \theta_3\beta_3}{\theta_1 + \theta_3} = \bar{\beta} - \theta_2(\beta_2 - \bar{\beta}). \tag{303}$$

   If $\beta_2 \geq \bar{\beta}$, then analogous to the first case, we also have $\beta^{EP}(\mathcal{I}) < \beta^{NC}$. Thus, it cannot be optimal. On the other hand, if $\beta_2 < \bar{\beta}$, then only $(p^{NC}_{IR,3}, \delta^{NC}_{IR,3})$ can be the optimal contract. However, under this contract, we have $\beta^{NC} = \beta_3$, which is greater than $\beta^{EP}(\mathcal{I})$. As such, this information withholding policy cannot be optimal either.

3. if the insurer withholds information when $i = 2, 3$, i.e., $\mathcal{I} = \{2, 3\}$, then we have

$$\beta^{EP}(\mathcal{I}) = \bar{\beta}. \tag{304}$$

   According to Lemma 3, for the insurer to exert effort, we must have $\beta^{NC} \geq \bar{\beta}$. As such, we have again that $\beta^{EP} \leq \beta^{NC}$. Therefore, this information withholding policy cannot be optimal either.

In summary, we have shown that under all possible optimal non-cancelable contracts, no information withholding policy is optimal. As such, the insurer should voluntarily disclose all information.

Similarly, under the optimal cancelable contract, according to Lemmas C.5 – C.7, all possible optimal cancelable contracts have $\beta^{CN} = \beta_3$. However, as we have shown, under all of the insurer' information withholding policies, $\beta^{EP}(\mathcal{I}) < \beta_3$. Thus, the necessary condition for information withholding in Lemma G.1 is not satisfied, and hence the insurer should voluntarily disclose all information under such contracts. □