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The Incentive Mechanism of Knowledge Sharing in Cross-Border Business Models Based on Digital Technologies

Yan Wang [1,*], Lifan Yang [2], Enzo Russo [3] and Domenico Graziano [3]

[1] School of Business, Honghe University, Mengzi 661199, China
[2] Faculty of Management and Economics, Kunming University of Science and Technology, Kunming 650031, China; yanglifanuse@outlook.com
[3] Department of Economics, University of Campania Luigi Vanvitelli, 80100 Naples, Italy; enzo.russo@insead.edu (E.R.); domenico.graziano@unicampania.it (D.G.)
* Correspondence: yyth.wyj@outlook.com

Abstract: This paper aims to solve the time-constrained problems of knowledge sharing caused by geographical distance and cultural differences in cross-border business models by proposing a novel knowledge sharing model based on principal–agent theory. Given that digital technologies (DTs) can solve the information asymmetry issue, this paper analyses and compares the contract parameters given by the principal, the efforts of the agent, and the changes in the expected profits of both parties before and after the application of DTs and therefore discusses the influence of various relevant factors in incentive contracts; the relationship between the expected profit of both parties and the various relevant factors is analyzed through numerical simulations. The results show that, in cross-border business models considering the time value of knowledge, the principal is affected not only by "information rent" and "channel loss" but also by the "time cost". The application of DTs can effectively reduce all three of these costs. More importantly, the principal's incentive coefficient and the agent's effort are related to this time constraint and the application of DTs.

Keywords: knowledge sharing; cross-border business models; digital technologies; principal–agent theory

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1. Introduction

With global economic integration, cross-border business models (CBBM) have gradually become a hot issue in academic circles [1]. Meanwhile, multinational corporations have increasingly become controllers of the world economic lifeline [2,3]. However, as Martin Christopher [4] (pp. 13–16), a famous British supply chain management expert, pointed out, "The competition in the 21st century is not between the individual enterprises, but between the supply chains". In addition, with the vigorous development of digital technologies (DTs) such as big data, blockchain, and artificial intelligence, knowledge sharing (KS) is gradually becoming an essential resource for the core competitiveness of enterprises [5]. Suppose that enterprises and the whole supply chain want to obtain a competitive advantage in the market in a knowledge economy. In that case, knowledge management (KM) becomes very important [6–8].

The term business model was used for the first time by R. Bellman, C. E. Clark, D. G. Malcolm, C. J. Craft, and F. M. Ricciardi [9] in 1957; since then, it has been frequently and near-inflationarily used in the economic field by scholars and business managers [10]. The most famous of them is Michael E. Porter [11] (pp. 63–78), who stated the following in 2001: "The definition of a business model is murky at best. It often seems to refer to a loose conception of how a company does business and generates revenue". It can be defined as structured management tools, which are critical points for success. Most of the 765 senior corporate executives in an IBM global study confirmed this assessment [12]. Accordingly, business models enjoyed great attention in both theoretical and practical fields [10,13,14].

However, as Teece, David J. [15] (pp. 172–194) stated, "the concept of a business models lacks theoretical grounding in economics or business studies"; there is still a relative lack of understanding of business models [16] and still a failure to converge towards a common understanding of the concept [10,17]. Through a literature review [18–24], we agreed that a business model is a multidimensional concept that spans various organizations' units, functions, and processes (supply chain). It focuses on building value creation and an incentive system from a dynamic perspective to improve the performance and competitiveness of its stakeholders and the whole chain. Nonetheless, recently, the rapid development of DTs has accelerated the flow of knowledge, capital, and resources on a global scale. The resulting CBBM has become a focal topic in theory and practice [24–26]. However, in cross-border organizations, the problem of information asymmetry caused by geographical distance and cultural differences is widespread, and it is more prominent than in general supply chain organizations [27–30]. Knowledge sharing is a typical principal–agent relationship. Scholars have widely discussed how to use principal–agent theory to explain the incentive of KS among organizations [30–32]. This paper explores the impact of considering the time attribute of knowledge and the application of DTs on the principal–agent relationship.

In reality, the accelerated, broader, and deeper intercultural interactions among stakeholders in CBBM, driven by information technology, also continue to challenge current knowledge and to break KS routines. Time becomes a factor that must be considered in sharing knowledge in cross-border supply chains [33]. In practice, many enterprises have relatively weak abilities to independently innovate and to acquire knowledge. Based on this, KS, the most crucial topic in KM, is a widespread concern of enterprises and academia [34,35]. Therefore, creating an effective KS incentive mechanism that can stimulate the "initiative" of supply chain stakeholders will positively influence the quality and speed of knowledge dissemination in the whole organization.

To sum up, KS in multi-organizations is a current research hotspot. The transformation of DTs to KM in the supply chain has also been widely discussed. According to a literature search, although many scholars have studied the incentive mechanism of KS in the supply chain by establishing a principal–agent relationship, they are merely studies considering a CBBM scenario, which includes the current trends and the knowledge time attribute. For the latter, it means the value of knowledge will change sharply with the passage of time [36–38]. Drawing on previous studies, particularly the research framework mentioned by Treiblmaier, H. [27], as shown in Figure 1, this study establishes a principal–agent model to study the KS incentive model considering knowledge time attribute (time constraint) by applying DTs in CBBM and tries to answer the following four questions:

(1) How do the expected benefits for principals and agents change in a CBBM that considers time constraints?
(2) What is the difference between the agent's efforts and the incentive contract given by the principal compared with the general situation?
(3) Are there other costs associated with time constraints in CBBM besides "information rent" and "channel loss"? If any, what are the losses?
(4) What are the new changes in "information rent" and "access loss" for principals after applying DTs? What are the implications of DTs for different types of costs for agents?

Correspondingly, this paper focuses on the following:

Analyzing the time properties of knowledge in CBBM: In this paper, we propose that, for the principal, the temporal properties of knowledge in CBBM are primarily temporal thresholds, i.e., before which the agent's KS is useful and after which the agent's KS is no longer beneficial or meaningful to the principal. For the agent, the temporal properties of knowledge are mainly manifested in the agent's ownership of proprietary knowledge before KS (which often generates excess profits) and the resulting loss to the agent after KS when proprietary knowledge becomes shared knowledge. Section 4 analyzes the incentive problem considering the temporal properties of principal and agent knowledge separately.

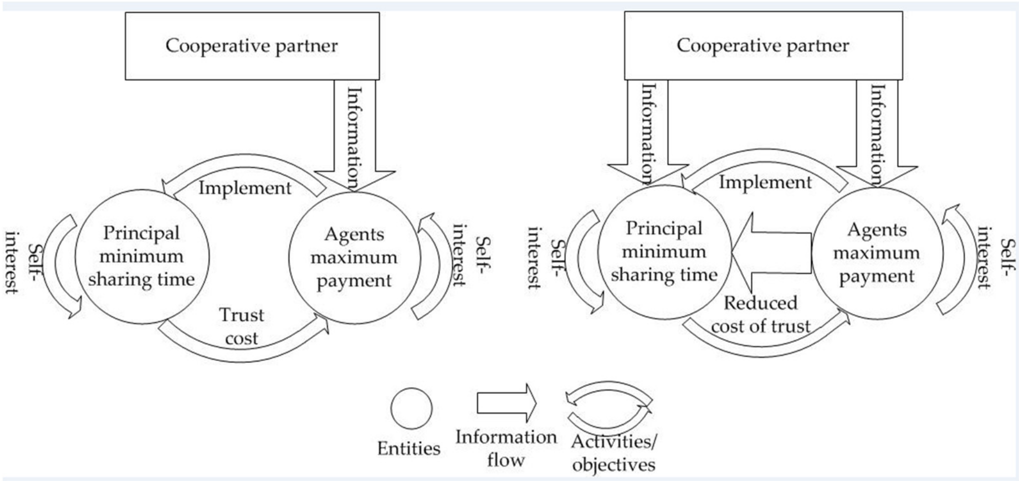

Figure 1. Principal–agent relationship before (**left**) and after (**right**) the application of DTs.

Impact of the application of DTs on the principal–agent relationship: As Treiblmaier, H. [27] stated, the application of DTs fundamentally changes the principal–agent relationship. In CBBM, how does the principal–agent relationship change with the application of DTs, and what are the implications for the principal and agent, separately? In Section 5, we analyze the incentive issues following the application of DTs.

The remainder of this article is organized as follows. Section 2 reviews the related literature. Section 3 describes the models and sets out the assumptions, while Section 4 designs incentive contracts to consider time constraints from the agent–principal perspective. Section 5 considers the DTs to perform the monitoring mechanism, and Section 6 analyses the results through numerical simulations. Finally, the conclusions and the enlightenments to future related research are presented in Section 7.

2. Literature Review

This paper aims to solve the time-constrained problems of KS caused by geographical distance and cultural differences in CBBM by proposing a novel KS model based on principal–agent theory. At present, the research on KS in cross–organizations related to this paper mainly focuses on incentive, the time value of knowledge, and the impact of DT on KS. Next, this section focuses on KS incentive research in the supply chain, the time attribute of knowledge, and the development that DTs bring changes to KM in the supply chain. We also highlight the differences between our study and the extant literature in this section.

2.1. Knowledge Sharing Incentive Research in Supply Chain

Knowledge is power [6,39,40]. KM is increasingly a valuable management initiative used to enhance productivity and to generate wealth for organizations [7,41,42]. Michailova, S. and Husted, K. [43] found that personal knowledge secures individuals' economic means, preventing them from sharing knowledge because unique private knowledge can bring them additional benefits and the transfer of knowledge ownership leads to their loss of profit [6]. According to the "Rational Economic Man" assumption, the decision to share knowledge occurs when its results outweigh the costs as expected. This means that KS is greater when the rewards are higher than the costs [44]. KS is not simple information sharing. Only a small visible aspect of existing knowledge can be expressed in language and documents, which is only the tip of the iceberg. As only small visible aspects of existing knowledge that can be expressed in language and documentation surface as the tips of the icebergs, therefore, "sharing" in the CBBM not only tells the entrusting enterprises what they (the agents) know but also encourages them to share their contexts and to create new means through interactions in an enlarged manner [24]. The entities in the supply chain are both cooperative and independent, which leads to the fact that enterprises in the same supply chain often have relatively "private" knowledge. This "private" knowledge is often an essential resource for enterprises to obtain a competitive advantage [45,46]. For example, retailers usually master the knowledge of customers' consumption habits, preferences, and tendencies, but manufacturers cannot fully master this knowledge. If manufacturers want to use this knowledge, KS has become an inevitable process. KS helps organizations identify best practices and promotes new ideas and organizational learning [47].

Scholars have conducted a lot of research on the incentive of KS in the supply chain from many concerns, such as knowledge structure, internal and external organization, incentive means, and environmental variables [48]. Through the empirical investigation of 120 enterprises in Southeast China, Jen et al. [49] found that trust and risk-sharing contracts can increase the possibility of KS among supply chain partners and can improve the overall supply chain performance. Wang et al. [50] established a principal–agent model to study the incentive conditions for KS among employees while considering explicit material incentive factors and implicit spiritual incentive factors [51]. Isik et al. [52] explored the role of tacit KS in technology transfer and international partnerships, and its role in team culture and innovative work behavior. Li, G. [53] discussed the influence mechanism of supply chain relationship quality on KS and enterprise innovation performance in the process of supply chain collaborative innovation by establishing the conceptual model of supply chain relationship quality, KS, and enterprise innovation performance. Wang et al. [32] studied the KS incentive mechanism of the industrial construction supply chain considering the knowledge structure under the supervision mechanism. Their research believes that the supervision mechanism can effectively encourage agents to make more extraordinary efforts. However, their KS models tend to have mechanical and general incentive mechanisms, lacking research on the models and mechanisms to stimulate their "initiative". As Allred, B. B. [54] (pp. 161–162) said, "knowledge workers cannot be bullied into creativity or information sharing, and the traditional forms of compensation and organizational hierarchy do not motivate people sufficiently for them to develop the strong relationships required for knowledge creation continuingly". This is also suitable for enterprises under the CBBM.

One of our main contribution is establishing an effective incentive mechanism for KS that positively influences the quality and speed of the dissemination of new knowledge by the whole cross-border organization and that can tear down national boundaries and help individual enterprises or the supply chain to which it belongs become more competitive.

2.2. The Time Attribute of Knowledge

The idea that knowledge has value is ancient [55,56]. Bozeman, B. and Rogers, J. D. [36]; Botelho, T. L. [37]; and Nerkar, A. [38] recognized the time value of knowledge. That is, the value of knowledge changes sharply with the passage of time. For many enterprises, their "unique" knowledge is often timely [29], such as the popular trend in sales seasons. The temporal properties of knowledge have been widely discussed by scholars, such as Poleacovschi, C. et al. [57] and its references. Therefore, the sharer must share the knowledge before using it, so that the learners can have sufficient time to absorb the knowledge. In addition, how much knowledge must be shared is related to the industry to which the knowledge belongs and to the abilities of the knowledge sharer and the learners, and here, we define this time as the "lead time". Knowledge is the source of profit for enterprises but has a significant time attribute. However, in the CBBM, there are cognitive differences in culture, belief, and even religion among stakeholders in the supply chain. The conventional mechanical incentive mechanism is not conducive to stimulating their "subjective initiative" for sharing [58]. In addition to considering the linear characteristics of time [1,59], Bakker et al. [60] and Berends et al. [61] studied the timing of KS. Therefore, the core enterprise of the supply chain, i.e., the principal, needs to encourage its partners, i.e., the agent, to share their unique knowledge; to meet the speed-oriented, time-multilateral market implications, and to meet the CBBM time-value orientation.

The main difference between those studies and ours is that the incentive mechanism of KS under a CBBM of enterprises is studied and had great practical significant. As mentioned before, many scholars have conducted a lot of research on the incentive of KS in the supply chain, but there are relatively few studies considering the knowledge time attribute (time constraint) of the agent and the principal, especially in the CBBM. Our research makes up for this gap.

2.3. The Development of DTs Brings Changes to Knowledge Management in the Supply Chain

Meanwhile, with the development of DTs, the problems of opaque, difficult tracing and wanton tampering with information in the supply chain have been solved at the technical level [27]. However, in reality, facilitated by ICTs, the accelerated, wider, and deeper intercultural interactions among stakeholders of a business model also constantly challenge current knowledge and break KS routines because the institutional logic underlying how knowledge is sourced, transformed, transferred, and deployed may vary or may not always make sense under heterogeneous cultures [24,62,63]. Moreover, cultural values also affect individuals' time perception as monochronism and polychronism, as these values shape how people assess the economic value attached to time [64]. In practice, many companies and industries actively use DTs to solve problems such as trust, information transparency, traceability, etc. [27]. The development of DTs has brought revolutionary changes to knowledge management in the supply chain. As an important branch of contract theory used to realize incentive compatibility, the principal–agent model has attracted the attention of extensive academic circles. Many scholars believe that DTs bring changes to the supply chain, such as information transparency, easy traceability, and tamperability [28,65–67]. Traditional principal–agent theory is based on the premise of information asymmetry, but as Treiblmaier, H. [27] mentioned in his research review, the principal–agent relationship changes fundamentally after the application of DTs. Unfortunately, they seem to ignore the impact of DTs on KS [62]. In this context, research must be conducted to improve KM systems, which should better enhance the supply chain's competitiveness [68,69].

One of our main contribution includes the incentive contract design of KS under the cross-border business scenario with DTs, focusing on what influences the time constraints in the supply chain bring to the principal and agent in addition to the "information rent" and "channel loss" caused by information asymmetry and how the "information rent", "channel loss" and "time cost" change after the application of DTs.

3. Model Formulation

3.1. Model Descriptions and Assumptions

This paper is based on a CBBM consisting of a principal and two agents in a supply chain. In the supply chain, the agents have "unique" knowledge (e.g., information on market demand trends through sales experience), and the agents' "unique" knowledge can bring them more profits. The principal wants the agents to share their specific knowledge to grasp the market dynamics, and to organize production purposefully to capture more markets and to gain a competitive advantage. Based on this, the principal gives an incentive contract to motivate the agents to share knowledge in as timely of a manner as possible. However, the cost of sharing knowledge is not the same for two different agents, so the principal needs to design the incentive contract according to the agent, with different costs.

Due to geographical distance and cultural differences, the time required for KS in a multinational supply chain is extended, i.e., the "lead time" of KS mentioned above. Therefore, unlike general supply chains, the time constraint of KS in multinational supply chains must be considered.

Furthermore, due to the adoption of DTs, information in the supply chain becomes transparent and the trust model shifts from interpersonal trust to digital trust. Referring to Treiblmaier's [27] study, the principal–agent relationship in the context of DTs is shown in Figure 1.

The model is based on the following assumptions:

Hypothesis 1. *Inspired by the study of Nikoofal, M. E. and Gumus, M. [31], this study assumes that both principals and agents are risk neutral and seeks to maximize expected returns.*

Hypothesis 2. *To focus on the KS time risk, we assume that the agent's knowledge is whole (the impact of knowledge structure on sharing is not the focus of this study) but that the agent can make efforts to shorten the time of KS, which is related to the agent's level of effort.*

Hypothesis 3. *There are two types of agents in a supply chain, high capacity (low cost) and low capacity (high cost), and the principal does not know the specific type of each agent but knows the probability of the two different types of agents.*

Hypothesis 4. *Before adopting DTs, the agent may hide information about their efforts, but the principal is not aware of the behavior. In the context of DTs, the information between the parties becomes transparent and the principal is able to be used to observe the behavior of the agent, but the type of cost of the agent remains unknown to the principal.*

Hypothesis 5. *The higher the agent's effort, the shorter their supply time, i.e.,* $t'_\theta(e_\theta) \leq 0$*. To simplify the model, this paper assumes that the principal obtains the agent's exact effort, i.e.,* $f(t_\theta) = ue_\theta$ [70]*. The purpose of the principal is to incentivize the agent to make a greater effort to shorten the supply time at a reasonable cost. Similar to most scholars, this paper assumes that the incentive contract is a fixed payment plus incentive payment.*

$$g(e_\theta) = A_\theta + \beta_\theta e_\theta \tag{1}$$

where A_θ *is the fixed payment and* β_θ *is the incentive factor.*

3.2. Symbols and Definitions

The symbols used in the paper and their definitions are shown in Table 1.

Table 1. Model parameter settings.

Symbols	Definition	Remarks
θ	Agent type, $\theta \in \{\overline{\theta}, \underline{\theta}\}$	$\overline{\theta}$ represents low cost $\underline{\theta}$ represents high cost
α_θ	Cost of effort factor for agents	$\alpha_{\overline{\theta}} \leq \alpha_{\underline{\theta}}$
u	Revenue factor of the principal	
γ	Time value factor of "unique" knowledge owned by the agent	
c_B	Cost of DT applications	
ρ	Proportion of low-cost proxy parties	
$\hat{e}_\theta$	Level of effort in selecting another type of contract menu by a type θ agent	
e'	Delegate's time constraint corresponds to the level of effort constraint	
$E(\pi_b)$	Expected return of the principal	
$E(\pi_{s\theta})$	Expected benefits for the agent of type θ	
Decision Variables		
e_θ	The level of effort used by the agent of type θ in selecting the corresponding contract	
A_θ	Fixed payments for incentive contracts that the principal gives to the type θ agent	
β_θ	The incentive coefficient of the incentive contract given by the principal to the type θ agent	

Note: In the formulas used below, the subscript s represents the supply side (agent) and the subscript b represents the buyer (principal). The superscript fb indicates a scenario without time constraints under information symmetry, the superscript sb indicates a scenario without time constraints under information asymmetry, the superscript tb indicates a scenario with time constraints considering the agent, the superscript lb indicates a scenario with time constraints considering the principal, and the superscript bc indicates the scenario after applying DTs.

3.3. Incentive Contract without Time Constraint (Benchmark Model)

As a benchmark model, we first consider the incentive contract when there is no time constraint (no consideration of the time value of shared knowledge). The agent only needs to pay the cost of the efforts without considering the loss of profit from sharing their "proprietary" knowledge. The principal only needs to consider designing reasonable contract parameters to maximize their profit without considering their time constraints. The time constraint here means that the principal needs time to prepare for the production before the production cycle starts, which we call "lead time". When the shared time is in this "lead time", even if the new knowledge is acquired, it is not possible to finish the production process of the production cycle. That is, the new knowledge acquired during the "lead time" does not bring additional profits to the manufacturer.

3.3.1. Incentive Contracts without Considering Time Constraints under Information Symmetry

We consider an information symmetric scenario in which the principal knows the type of KS cost of the agents and observes their effort actions, and the principal only needs to design different contract menus for different types of agents to maximize their expected benefits. The agent only needs to determine the level of effort according to the principal's contract menu to maximize the expected revenue. The principal–agent model in this scenario is as follows

$$\max_{(A_\theta,\beta_\theta)} E(\pi_b) = ue_\theta - A_\theta - \beta_\theta e_\theta$$
$$s.t.\begin{cases} A_\theta + \beta_\theta e_\theta - \frac{1}{2}\alpha_\theta {e_\theta}^2 \geq 0, \theta \in \{\overline{\theta}, \underline{\theta}\}(IR) \\ e_\theta \geq 0 \end{cases} \tag{2}$$

Obviously, the principal only needs to let the personal rationality constraint reach tautness (taking the equal sign) according to the personal rationality constraint.

$$A_\theta + \beta_\theta e_\theta^{fb} - \frac{1}{2}\alpha_\theta e_\theta^{fb2} = 0 \tag{3}$$

Substituting Equation (3) into Equation (2), we obtain the following:

$$\begin{cases} e_\theta^{fb} = \frac{u}{\alpha_\theta} \\ \beta_\theta^{fb} = 0 \\ A_\theta^{fb} = \frac{1}{2}\frac{u^2}{\alpha_\theta} \end{cases} \tag{4}$$

The expected benefits for the principal and the agents, respectively, are as follows:

$$\begin{cases} E(\pi_{b\theta}^{fb}) = \frac{1}{2}\frac{u^2}{\alpha_\theta} \\ E(\pi_s^{fb}) = 0 \end{cases} \tag{5}$$

$$\begin{cases} e_{\underline{\theta}}^{fb} \leq e_{\overline{\theta}}^{fb} \\ E(\pi_{b\underline{\theta}}^{fb}) \leq E(\pi_{b\overline{\theta}}^{fb}) \end{cases} \tag{6}$$

Under information symmetry, as shown in Equation (6), when the agent's KS cost is lower, the level of effort and expected benefit to the principal are higher. The principal then gives a fixed payment contract and takes all of the benefits. Of course, this contract is valid under the information symmetry condition, and the fixed payment of the contract is then just equal to the agent's cost.

3.3.2. Incentive Contracts without Considering Time Constraints under Information Asymmetry

In this context, the principal neither knows the agent's cost type nor observes any effortful actions. Thus, the principal designs the contractual menu to motivate different types of agents to make the optimal level of effort to maximize the expected benefits. Nikoofal, M. E. and Gumus, M. [31] provided the procedure for using the principal–agent theory.

First, the agent must determine the optimal level of effort to maximize their own expected benefits based on the contractual menu given by the principal:

$$e_{\theta}^{sb} = \underset{e_\theta}{\operatorname{argmax}}\left\{A_\theta + \beta_\theta e_\theta - \frac{1}{2}\alpha_\theta {e_\theta}^2\right\}, \theta \in \{\overline{\theta}, \underline{\theta}\}(IC-1,2) \tag{7}$$

Meanwhile, under the contract given by the principal, the requirement that the agent's expected return is nonnegative (assuming that all of the agent's retained returns are zero) is to be satisfied:

$$A_\theta + \beta_\theta e_\theta - \frac{1}{2}\alpha_\theta {e_\theta}^2 \geq 0, \theta \in \{\overline{\theta}, \underline{\theta}\}(IR-1,2) \tag{8}$$

Second, the optimal contract menu must satisfy the incentive-compatibility constraint (IC), ensuring that the θ supplier chooses the contract menu designed for it. It is important to note that, unlike shared time that can actually be observed, the agent's effort is not observed by the principal, i.e., whichever contract menu the agent chooses, it determines the level of effort based on its own revenue maximization condition rather than the level of effort corresponding to the contract menu [31]:

$$\begin{cases} A_{\underline{\theta}} + \beta_{\underline{\theta}} e_{\underline{\theta}}^{sb} - \frac{1}{2}\alpha_{\underline{\theta}} e_{\underline{\theta}}^{sb2} \geq A_{\overline{\theta}} + \beta_{\overline{\theta}} \hat{e}_{\underline{\theta}}^{sb} - \frac{1}{2}\alpha_{\underline{\theta}} \hat{e}_{\underline{\theta}}^{sb2}(IC-3) \\ A_{\overline{\theta}} + \beta_{\overline{\theta}} e_{\overline{\theta}}^{sb} - \frac{1}{2}\alpha_{\overline{\theta}} e_{\overline{\theta}}^{sb2} \geq A_{\underline{\theta}} + \beta_{\underline{\theta}} \hat{e}_{\overline{\theta}}^{sb} - \frac{1}{2}\alpha_{\overline{\theta}} \hat{e}_{\overline{\theta}}^{sb2}(IC-4) \end{cases} \tag{9}$$

where $\hat{e}_{\overline{\theta}}^{sb}$ denotes the level of effort decided by the agent with cost type $\overline{\theta}$ for choosing contract menu $\left(A_{\underline{\theta}}, \beta_{\underline{\theta}}\right)$ based on the principle of maximizing their own revenue. Similarly $\hat{e}_{\underline{\theta}}^{sb}$, we obtain the following

$$\begin{cases} \hat{e}_{\overline{\theta}}^{sb} = \underset{e_{\overline{\theta}}}{\operatorname{argmax}}\left\{A_{\underline{\theta}} + \beta_{\underline{\theta}} e_{\overline{\theta}} - \frac{1}{2}\alpha_{\overline{\theta}} {e_{\overline{\theta}}}^2\right\}(IR-3) \\ \hat{e}_{\underline{\theta}}^{sb} = \underset{e_{\underline{\theta}}}{\operatorname{argmax}}\left\{A_{\overline{\theta}} + \beta_{\overline{\theta}} e_{\underline{\theta}} - \frac{1}{2}\alpha_{\underline{\theta}} {e_{\underline{\theta}}}^2\right\}(IR-4) \end{cases} \tag{10}$$

For the principal, the problem is to find the optimal contract menu that satisfies the above constraints:

$$\begin{array}{l} E(\pi_b) = \underset{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})}{\max}\left\{\rho\left(ue_{\overline{\theta}} - A_{\overline{\theta}} - \beta_{\overline{\theta}} e_{\overline{\theta}}\right) + (1-\rho)\left(ue_{\underline{\theta}} - A_{\underline{\theta}} - \beta_{\underline{\theta}} e_{\overline{\theta}}\right)\right\} \\ s.t. \text{ Constraints } (7-10) \end{array} \tag{11}$$

Proposition 1. *In the scenario of information asymmetry, there is a unique optimal solution for the optimal level of effort of high-cost and low-cost agents, the optimal contract menu of the principal,* *and the expected benefits obtained by the principal and the agent. As shown in Equations (12)–(14), respectively (see Appendix A for the solutions),*

$$\begin{cases} e^{sb}_{\underline{\theta}} = \frac{\alpha_{\overline{\theta}}(1-\rho)}{\alpha_{\overline{\theta}}(1-\rho)+\rho\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)} \frac{u}{\alpha_{\underline{\theta}}} \\ e^{sb}_{\overline{\theta}} = \frac{u}{\alpha_{\overline{\theta}}} \end{cases} \tag{12}$$

$$\begin{cases} \beta^{sb}_{\underline{\theta}} = \frac{\alpha_{\overline{\theta}}(1-\rho)}{\alpha_{\overline{\theta}}(1-\rho)+\rho\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)} u \\ \beta^{sb}_{\overline{\theta}} = u \\ A^{sb}_{\underline{\theta}} = -\frac{1}{2}\frac{\beta^{sb2}_{\underline{\theta}}}{\alpha_{\underline{\theta}}} \\ A^{sb}_{\overline{\theta}} = -\frac{1}{2}\frac{u^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\beta^{sb2}_{\underline{\theta}}\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right) \end{cases} \tag{13}$$

$$\begin{cases} E\left(\pi^{sb}_{s\underline{\theta}}\right) = 0 \\ E\left(\pi^{sb}_{s\overline{\theta}}\right) = \frac{1}{2}\left(\frac{\alpha_{\overline{\theta}}(1-\rho)}{\alpha_{\overline{\theta}}(1-\rho)+\rho\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)} u\right)^2\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right) \geq 0 \\ E\left(\pi^{sb}_{b}\right) = \rho\left(\frac{1}{2}\frac{u^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\beta^{sb2}_{\underline{\theta}}\left(\frac{1}{\alpha_{\underline{\theta}}} - \frac{1}{\alpha_{\overline{\theta}}}\right)\right) + (1-\rho)\left(u\frac{\beta^{sb}_{\underline{\theta}}}{\alpha_{\underline{\theta}}} - \frac{1}{2}\frac{\beta^{sb2}_{\underline{\theta}}}{\alpha_{\underline{\theta}}}\right) \end{cases} \tag{14}$$

Proposition 2. *According to Equation (12), under information asymmetry, the effort of high-cost agents decreases compared with information symmetry, which leads to a lower expected return for the principal. The "channel loss" is also related to the proportion of different cost types of agents, and the principal suffers less "channel loss" if the proportion of low-cost agents is smaller (proof omitted).*

Proposition 2 illustrates that, under information asymmetry, the principal suffers a "channel loss" (loss due to reduced effort) as a result of the high-cost agent. In fact, comparing the expected benefit of the high-cost agent in Equation (14) with the expected benefit of the high-cost agent in Equation (5), we find that the principal does receive a lower expected benefit (see Equation (A12) in Appendix A for the results). From Equation (12), the mathematical reason is that the effort cost coefficients of the two different types of agents are different $\left(\alpha_{\underline{\theta}} \neq \alpha_{\overline{\theta}}\right)$, leading to the emergence of "channel loss". The economic management reason is that, since two different types of agents have different effort cost coefficients, if the principal increases the incentive coefficient of the high-cost agent to motivate it to increase their effort, it inevitably leads the low-cost agent to imitating the high-cost agent and thus the principal obtains less expected revenue from the low-cost agent. This is because a single low-cost agent brings a higher expected return to the principal. Therefore, under the scenario of information asymmetry, the principal can only try to "capture" the "higher" expected returns from the low-cost agent and has to tolerate the lower effort of the high-cost agent and the resulting "channel loss".

Proposition 3. *According to Equations (12) and (13), the effort of the low-cost agent remains the same compared with the case of information symmetry, but the principal's wage paid to the low-cost agent increases, i.e., the information asymmetry generates "information rent" for the principal (proof omitted).*

Proposition 3 illustrates that, in a scenario of information asymmetry, in order to incentivize the low-cost agent to make "optimal" efforts, the principal has to pay extra wages to the low-cost agent because of the information asymmetry. The reason is that, when information is asymmetric, the low-cost agent has an incentive to imitate the high-cost agent and the principal has to pay the low-cost agent a higher wage in order to motivate them to make an "optimal" effort.

As in previous studies, "information rent" and "access loss" together constitute the total loss to the principal in the information asymmetry scenario.

4. Incentive Contract Design of Knowledge Sharing Consider Time Constraint

In this section, we design contracts that consider time constraints for the agent and principal, separately. By modeling the principal–agent model when the agent and principal have time constraints, we analyze the effects on the contract parameters, effort, and expected profit obtained by the principal and agent.

4.1. The Incentive Contract When Considering the Agent's Time Constraint

In this case, considering that the agent has a time constraint, the agent gains "excess" profits because they have "exclusive" knowledge. However, when the agent shares their knowledge with the principal, this additional profit disappears because the "exclusive" knowledge becomes "public" knowledge. In other words, the agent suffers from additional losses in addition to the effort cost of KS.

$$c_s = \frac{1}{2}\alpha_\theta {e_\theta}^2 + \gamma e = \frac{1}{2}\alpha_\theta {e_\theta}^2 + \gamma e_\theta, \theta \in \{\overline{\theta}, \underline{\theta}\} \tag{15}$$

where c_s denotes the total cost suffered by the agent in KS and γ is the additional profit factor generated by the agent's unique knowledge.

Thus, Equations (7)–(10) can be rewritten, respectively, as follows.

$$e_\theta^{tb} = \underset{e_\theta}{\operatorname{argmax}}\left\{A_\theta + \beta_\theta e_\theta - \frac{1}{2}\alpha_\theta {e_\theta}^2 - \gamma e_\theta\right\}, \theta \in \{\overline{\theta}, \underline{\theta}\}(IC-1,2) \tag{16}$$

$$A_\theta + \beta_\theta e_\theta - \frac{1}{2}\alpha_\theta {e_\theta}^2 - \gamma_\theta e_\theta \geq 0, \theta \in \{\overline{\theta}, \underline{\theta}\}(IR-1,2) \tag{17}$$

$$\begin{cases} A_{\underline{\theta}} + \beta_{\underline{\theta}} e_{\underline{\theta}}^{tb} - \frac{1}{2}\alpha_{\underline{\theta}} e_{\underline{\theta}}^{tb2} - \gamma e_{\underline{\theta}}^{tb} \geq A_{\overline{\theta}} + \beta_{\overline{\theta}} \hat{e}_{\underline{\theta}}^{tb} - \frac{1}{2}\alpha_{\underline{\theta}} \hat{e}_{\underline{\theta}}^{tb2} - \gamma \hat{e}_{\underline{\theta}}^{tb}(IC-3) \\ A_{\overline{\theta}} + \beta_{\overline{\theta}} e_{\overline{\theta}}^{tb} - \frac{1}{2}\alpha_{\overline{\theta}} e_{\overline{\theta}}^{tb2} - \gamma e_{\overline{\theta}}^{tb} \geq A_{\underline{\theta}} + \beta_{\underline{\theta}} \hat{e}_{\overline{\theta}}^{tb} - \frac{1}{2}\alpha_{\overline{\theta}} \hat{e}_{\overline{\theta}}^{tb2} - \gamma \hat{e}_{\overline{\theta}}^{tb}(IC-4) \end{cases} \tag{18}$$

$$\begin{cases} \hat{e}_{\overline{\theta}}^{tb} = \underset{e_{\overline{\theta}}}{\operatorname{argmax}}\left\{A_{\underline{\theta}} + \beta_{\underline{\theta}} e_{\overline{\theta}} - \frac{1}{2}\alpha_{\overline{\theta}} {e_{\overline{\theta}}}^2 - \gamma e_{\overline{\theta}}\right\}(IR-3) \\ \hat{e}_{\underline{\theta}}^{tb} = \underset{e_{\underline{\theta}}}{\operatorname{argmax}}\left\{A_{\overline{\theta}} + \beta_{\overline{\theta}} e_{\underline{\theta}} - \frac{1}{2}\alpha_{\underline{\theta}} {e_{\underline{\theta}}}^2 - \gamma e_{\underline{\theta}}\right\}(IR-4) \end{cases} \tag{19}$$

As a result, the principal–agent model of Equation (11) can be rewritten as

$$\begin{aligned} &E(\pi_b) = \max_{(A_{\overline{\theta}}, \beta_{\overline{\theta}}), (A_{\underline{\theta}}, \beta_{\underline{\theta}})} \left\{\rho\left(ue_{\overline{\theta}} - A_{\overline{\theta}} - \beta_{\overline{\theta}} e_{\overline{\theta}}\right) + (1-\rho)\left(ue_{\underline{\theta}} - A_{\underline{\theta}} - \beta_{\underline{\theta}} e_{\underline{\theta}}\right)\right\} \\ &s.t.\{\text{Constraints } (16-19) \end{aligned} \tag{20}$$

Proposition 4. *In the context of considering the agent's time constraint, the optimal degrees of effort of the high-cost and low-cost agents, the optimal contract menus of the principal, and the expected benefits obtained by the principal and the agent all have unique optimal solutions, as shown in Equations (26)–(28) respectively. The solutions are shown in Appendix B.*

$$\begin{cases} e_{\underline{\theta}}^{tb} = \frac{(1-\rho)\alpha_{\overline{\theta}}}{\alpha_{\overline{\theta}}(1-\rho) + \left(\alpha_{\underline{\theta}} - \alpha_{\overline{\theta}}\right)\rho} \frac{u-\gamma}{\alpha_{\underline{\theta}}} \\ e_{\overline{\theta}}^{tb} = \frac{u-\gamma}{\alpha_{\overline{\theta}}} \end{cases} \tag{21}$$

$$\begin{cases} \beta_{\underline{\theta}}^{tb} = \frac{(1-\rho)u\alpha_{\overline{\theta}}}{\alpha_{\overline{\theta}}(1-\rho) + \left(\alpha_{\underline{\theta}} - \alpha_{\overline{\theta}}\right)\rho} + \frac{\rho\gamma\left(\alpha_{\underline{\theta}} - \alpha_{\overline{\theta}}\right)}{\alpha_{\overline{\theta}}(1-\rho) + \left(\alpha_{\underline{\theta}} - \alpha_{\overline{\theta}}\right)\rho} \\ \beta_{\overline{\theta}}^{tb} = u \end{cases}$$
$$\begin{cases} A_{\underline{\theta}}^{tb} = -\frac{1}{2}\frac{\left(\beta_{\underline{\theta}}^{sb} - \gamma\right)^2}{\alpha_{\underline{\theta}}} \\ A_{\overline{\theta}}^{tb} = -\frac{1}{2}\frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}} - \frac{1}{2}\left(\beta_{\underline{\theta}}^{sb} - \gamma\right)^2\left(\frac{1}{\alpha_{\underline{\theta}}} - \frac{1}{\alpha_{\overline{\theta}}}\right) \end{cases} \tag{22}$$

$$\begin{cases} E(\pi_{s\underline{\theta}}^{tb}) = 0 \\ E(\pi_{s\overline{\theta}}^{tb}) = \frac{1}{2}\left(\frac{(1-\rho)\alpha_{\overline{\theta}}}{\alpha_{\overline{\theta}}(1-\rho)+\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)\rho}(u-\gamma)\right)^2\left(\frac{1}{\alpha_{\overline{\theta}}}-\frac{1}{\alpha_{\underline{\theta}}}\right) \geq 0 \\ E(\pi_b^{tb}) = \rho\left(\frac{1}{2}\frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}}+\frac{1}{2}\left(\beta_{\underline{\theta}}^{sb}-\gamma\right)^2\left(\frac{1}{\alpha_{\underline{\theta}}}-\frac{1}{\alpha_{\overline{\theta}}}\right)\right) \\ +(1-\rho)\left(\left(u-\beta_{\underline{\theta}}^{sb}\right)\frac{\left(\beta_{\underline{\theta}}^{sb}-\gamma\right)}{\alpha_{\underline{\theta}}}+\frac{1}{2}\frac{\left(\beta_{\underline{\theta}}^{sb}-\gamma\right)^2}{\alpha_{\underline{\theta}}}\right) \end{cases} \tag{23}$$

Propositions 3 and 4 show that, when the agent's time constraint is considered, the agent's effort decreases while the principal's incentive coefficient increases. In contrast to the time constraint, the expected profit of the low-cost agent decreases but is still greater than 0. This is mainly because it is an unreasonable assumption not to consider the agent's time constraint. This is because it only takes into account the "compensation" for the effort cost of KS by the agent but not the cost of the loss of "unique knowledge" suffered by the agent. The profit of the principal is lower because they need to compensate more costs to the agent after considering the agent's time constraint. Of course, the principal still suffers from the "loss of access" and "information rent".

4.2. Considering the Principal Has a Constraint on the Agent's Knowledge Sharing Time

Furthermore, we consider the time constraint of the principal, i.e., for the principal, the value of knowledge generation is also time–dependent. In this paper, we assume that the principal has a production preparation time of $\bar{t}$, which is also referred to as the "lead time" in the previous section, and when the agent shares knowledge in the "lead time", the principal has to implement production as previous planned and then does not benefit from the KS. Therefore, the principal has a time constraint on KS. According to the previous assumptions, the principal's time constraint can be converted into an effort constraint and the agent's effort must be greater than or equal to the effort constraint corresponding to the principal's time constraint (hereafter referred to as the effort constraint):

$$t_\theta \leq \bar{t} \Rightarrow e_\theta \geq e', \theta \in \left\{\overline{\theta}, \underline{\theta}\right\} \tag{24}$$

where e' is the level of effort corresponding to the time constraint given by the principal.

From Section 4.1, $e_{\underline{\theta}}^{tb} \leq e_{\overline{\theta}}^{tb}$, there are three scenarios when considering the principal time constraint.

(1) When $e' \leq e_{\underline{\theta}}^{tb}$, the principal time constraint has no effect on the original principal–agent model, and the specific results are presented in Section 4.1.

(2) When $e_{\underline{\theta}}^{tb} \leq e' \leq e_{\overline{\theta}}^{tb}$, the original principal–agent model requires the addition of an effort constraint, and of course, since the principal's effort constraint is greater than their optimal effort $e_{\underline{\theta}}^{tb}$ for the high-cost agent, at this point, the high-cost agent's optimal effort is the principal's effort constraint e'. As a result, Equation (11) can be rewritten as follows:

$$\begin{aligned} E(\pi_b) &= \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{\rho\left(ue_{\overline{\theta}}-A_{\overline{\theta}}-\beta_{\overline{\theta}}e_{\overline{\theta}}\right)+(1-\rho)\left(ue_{\underline{\theta}}-A_{\underline{\theta}}-\beta_{\underline{\theta}}e_{\underline{\theta}}\right)\right\} \\ s.t. &\begin{cases} \text{Constraints } (16-19) \\ e_{\underline{\theta}}^{lb} \geq e' \end{cases} \end{aligned} \tag{25}$$

Proposition 5. *When the principal's effort constraint satisfies $e_{\underline{\theta}}^{tb} \leq e' \leq e_{\overline{\theta}}^{tb}$, the optimal effort of the high-cost and low-cost agents, the optimal contract menu of the principal, and the expected* *benefits obtained by the principal and the agent all have unique optimal solutions, as shown in Equations (26)–(28), respectively, which are solved in Appendix C.*

$$\begin{cases} e_{\underline{\theta}}^{lb} = e' \\ e_{\overline{\theta}}^{lb} = \frac{u-\gamma}{\alpha_{\overline{\theta}}} \end{cases} \tag{26}$$

$$\begin{cases} \beta_{\underline{\theta}}^{lb} = \alpha_{\underline{\theta}} e' + \gamma \\ \beta_{\overline{\theta}}^{lb} = u \\ A_{\underline{\theta}}^{lb} = -\frac{1}{2}\alpha_{\underline{\theta}} e'^2 \\ A_{\overline{\theta}}^{lb} = -\frac{1}{2}\frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\alpha_{\underline{\theta}} e'^2 \left(\frac{\alpha_{\underline{\theta}}}{\alpha_{\overline{\theta}}} - 1\right) \end{cases} \tag{27}$$

$$\begin{cases} E(\pi_{s\underline{\theta}}^{lb}) = 0 \\ E(\pi_{s\overline{\theta}}^{lb}) = \frac{1}{2}\left(\alpha_{\underline{\theta}} e'\right)^2 \left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right) \\ E(\pi_b^{lb}) = \rho\left(\frac{1}{2}\frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\left(\alpha_{\underline{\theta}} e'\right)^2 \left(\frac{1}{\alpha_{\underline{\theta}}} - \frac{1}{\alpha_{\overline{\theta}}}\right)\right) + (1-\rho)\left((u-\gamma)e' - \frac{1}{2}\alpha_{\underline{\theta}} e'^2\right) \end{cases} \tag{28}$$

Proposition 5 shows that, when the principal's effort constraint satisfies $e_{\underline{\theta}}^{tb} \le e' \le e_{\overline{\theta}}^{tb}$, the high-cost agent must increase their effort to continue participating in the supply chain. Accordingly, the principal changes the contract parameters accordingly so that the high-cost agent's gain remains 0. That is, contrary to our intuitive understanding, the principal's time constraint does not bring additional expected gains to the high-cost agent.

Proposition 6. *When the principal's effort constraint satisfies $e_{\underline{\theta}}^{tb} \le e' \le e_{\overline{\theta}}^{tb}$, the low-cost agent receives higher expected benefits while the principal pays higher costs (expected benefits become smaller compared with before the constraint). The proof is given in Appendix C.*

Proposition 6 illustrates that, when the principal has a time constraint, in order to incentivize the high-cost agent to increase their effort to meet the constraint, the principal needs to increase the high-cost agent's incentive coefficient so that the high-cost agent's expected return reaches their retained return (which is assumed to be zero in this paper). Meanwhile, in order to incentivize the low-cost agent not to imitate the behavior of the high-cost agent, the principal needs to pay a higher incentive cost to the low-cost agent in addition to the "information rent". Since this cost is caused by the time constraint of KS in the supply chain, we denote this cost as the "time cost". Of course, we believe that it is often worthwhile for commissioners to pay this high cost in order for KS to generate value.

(3) When $e' \ge e_{\overline{\theta}}^{tb}$, the high-cost and low-cost agents in the original principal–agent model need to add a degree of effort constraint. According to the previous analysis, we know that, when $e' \ge e_{\overline{\theta}}^{sb} \ge \hat{e}_{\overline{\theta}}^{tb} \ge \hat{e}_{\underline{\theta}}^{tb}$, whether it is a low-cost agent or a high-cost agent, the higher their effort, the smaller their expected return, so the effort of both low-cost and high-cost agents is only equal to e', and at this time, the incentive coefficient given by the principal is as follows:

$$\begin{cases} \beta_{\overline{\theta}}^{lb} - \gamma = \alpha_{\overline{\theta}} e' \\ \beta_{\underline{\theta}}^{lb} - \gamma = \alpha_{\underline{\theta}} e' \end{cases} \tag{29}$$

Therefore, the IC at this point becomes

$$\begin{cases} A_{\underline{\theta}} + \beta_{\underline{\theta}} e_{\underline{\theta}} - \frac{1}{2}\alpha_{\underline{\theta}} e_{\underline{\theta}}{}^2 - \gamma e_{\underline{\theta}} \ge A_{\overline{\theta}} + \beta_{\overline{\theta}} e' - \frac{1}{2}\alpha_{\underline{\theta}} e'^2 - \gamma e' (IC-1) \\ A_{\overline{\theta}} + \beta_{\overline{\theta}} e_{\overline{\theta}} - \frac{1}{2}\alpha_{\overline{\theta}} e_{\overline{\theta}}{}^2 - \gamma e_{\overline{\theta}} \ge A_{\underline{\theta}} + \beta_{\underline{\theta}} e' - \frac{1}{2}\alpha_{\overline{\theta}} e'^2 - \gamma e' (IC-2) \end{cases} \tag{30}$$

Meanwhile, the original principal–agent model becomes

$$E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{\rho\left(ue_{\overline{\theta}} - A_{\overline{\theta}} - \beta_{\overline{\theta}}e_{\overline{\theta}}\right) + (1-\rho)\left(ue_{\underline{\theta}} - A_{\underline{\theta}} - \beta_{\underline{\theta}}e_{\underline{\theta}}\right)\right\}$$
$$s.t. \begin{cases} e^{lb}_{\overline{\theta}} \geq e' \\ e^{lb}_{\underline{\theta}} \geq e' \\ \text{Constraints } (17, 30, 31) \end{cases} \tag{31}$$

Proposition 7. *When the effort constraint of the principal satisfies $e' \geq e^{tb}_{\overline{\theta}}$, there is a unique optimal solution for each parameter of the principal and agent, as shown in Equations (32)–(34). (See Appendix D for the solution).*

$$\begin{cases} \beta^{lb}_{\underline{\theta}} = \alpha_{\underline{\theta}}e' + \gamma \\ \beta^{lb}_{\overline{\theta}} = \alpha_{\overline{\theta}}e' + \gamma \\ A^{lb}_{\underline{\theta}} = -\frac{1}{2}\alpha_{\underline{\theta}}e'^2 \\ A^{lb}_{\overline{\theta}} = -\frac{1}{2}\alpha_{\overline{\theta}}e'^2 + \frac{1}{2}\left(\alpha_{\underline{\theta}}e'\right)^2\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right) \end{cases} \tag{32}$$

$$\begin{cases} e^{lb}_{\underline{\theta}} = e' \\ e^{lb}_{\overline{\theta}} = e' \end{cases} \tag{33}$$

$$\begin{cases} \pi^{lb}_{s\underline{\theta}} = 0 \\ \pi^{lb}_{s\overline{\theta}} = \frac{1}{2}(\alpha_{\underline{\theta}}e')^2\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right) \\ E(\pi^{lb}_b) = \rho\left((u-\gamma)e' - \frac{1}{2}\alpha_{\underline{\theta}}e'^2\left(\frac{\alpha_{\overline{\theta}}}{\alpha_{\underline{\theta}}} + \frac{\alpha_{\underline{\theta}}}{\alpha_{\overline{\theta}}} - 1\right)\right) + (1-\rho)\left((u-\gamma)e' - \frac{1}{2}\alpha_{\underline{\theta}}e'^2\right) \end{cases} \tag{34}$$

Proposition 7 suggests that the original principal–agent problem fundamentally changed. This is because the principal's effort constraint exceeded the maximum level of effort of the agent (regardless of whether the cost type is high or low) in the unconstrained case. That is, the principal no longer needs to determine what the most appropriate level of effort is for them but only to determine whether the contract parameters given by the agent are profitable. If the contract parameters are profitable, then the contract is executed; if not, then the execution of the contract is abandoned. There is no doubt that this "almost unconscionable" time limit for the principal also costs a lot of money.

5. Incentive Optimization Model Based on Supervisory Mechanism (after Applying DTs)

In this section, we consider the principal performing the monitoring mechanism, and in this paper, we assume that the principal applies DTs in order to monitor agents. After applying DTs, the principal can observe information about the agent's behavior but still cannot observe the type of cost of the agent, and applying DTs brings additional cost to the principal.

5.1. Consider Only the Agent's Time Constraints after Applying DTs

With the application of DTs, the principal is able to observe the agent's effort actions [31], although, unlike the information symmetry case in which the principal knows the agent's cost type, the application of DTs does not observe the agent's cost type. Therefore, at this point, the IC changes, and when the agent chooses contract menus designed for an agent of another cost type (e.g., the low-cost agent chooses the contract parameters designed for the high-cost agent), their level of effort is no longer determined according to their own revenue maximization principle but according to the optimal level of effort of the high-cost agent, and then, the IC constraint becomes

$$\begin{cases} A_{\underline{\theta}} + \beta_{\underline{\theta}} e^*_{\underline{\theta}} - \frac{1}{2}\alpha_{\underline{\theta}} e^{*2}_{\underline{\theta}} - \gamma e^*_{\underline{\theta}} \geq A_{\overline{\theta}} + \beta_{\overline{\theta}} e^*_{\overline{\theta}} - \frac{1}{2}\alpha_{\underline{\theta}} e^{*2}_{\overline{\theta}} - \gamma e^*_{\overline{\theta}} (IC-1) \\ A_{\overline{\theta}} + \beta_{\overline{\theta}} e^*_{\overline{\theta}} - \frac{1}{2}\alpha_{\overline{\theta}} e^{*2}_{\overline{\theta}} - \gamma e^*_{\overline{\theta}} \geq A_{\underline{\theta}} + \beta_{\underline{\theta}} e^*_{\underline{\theta}} - \frac{1}{2}\alpha_{\overline{\theta}} e^{*2}_{\underline{\theta}} - \gamma e^*_{\underline{\theta}} (IC-2) \\ e^*_{\underline{\theta}} = \underset{e_{\underline{\theta}}}{\operatorname{argmax}} \left\{ A_{\underline{\theta}} + \beta_{\underline{\theta}} e_{\underline{\theta}} - \frac{1}{2}\alpha_{\underline{\theta}} e_{\underline{\theta}}{}^2 - \gamma e_{\underline{\theta}} \right\} (IC-3) \\ e^*_{\overline{\theta}} = \underset{e_{\overline{\theta}}}{\operatorname{argmax}} \left\{ A_{\overline{\theta}} + \beta_{\overline{\theta}} e_{\overline{\theta}} - \frac{1}{2}\alpha_{\overline{\theta}} e_{\overline{\theta}}{}^2 - \gamma e_{\overline{\theta}} \right\} (IC-4) \end{cases} \tag{35}$$

Meanwhile, the nonnegative constraint on the agent's expected return and the revenue maximization constraint remain unchanged. However, since there is an additional cost for the principal to apply DTs to perform supervision, at this point, the principal–agent model becomes

$$\begin{aligned} &E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{ \rho\left(ue_{\overline{\theta}} - A_{\overline{\theta}} - \beta_{\overline{\theta}} e_{\overline{\theta}}\right) + (1-\rho)\left(ue_{\underline{\theta}} - A_{\underline{\theta}} - \beta_{\underline{\theta}} e_{\underline{\theta}}\right) - c_B \right\} \\ &s.t.\{\text{Constraints } (16, 35) \end{aligned} \tag{36}$$

Proposition 8. *Under DTs, when considering the time constraint of the agent, there is a unique optimal solution for the contract parameters given by the principal, the degree of effort of the agent, and the expected revenue of each party, as shown in Equations (37)–(39), respectively. (See Appendix E for the solutions).*

$$\begin{cases} e^{bc}_{\underline{\theta}} = \frac{(1-\rho)\alpha_{\underline{\theta}}}{\alpha_{\underline{\theta}} - \rho\alpha_{\overline{\theta}}} \left(\frac{u-\gamma}{\alpha_{\underline{\theta}}}\right) \\ e^{bc}_{\overline{\theta}} = \frac{u-\gamma}{\alpha_{\overline{\theta}}} \end{cases} \tag{37}$$

$$\begin{cases} \beta^{bc}_{\underline{\theta}} = \frac{(1-\rho)\alpha_{\underline{\theta}}}{\alpha_{\underline{\theta}} - \rho\alpha_{\overline{\theta}}} u + \frac{\rho\left(\alpha_{\underline{\theta}} - \alpha_{\overline{\theta}}\right)}{\alpha_{\underline{\theta}} - \rho\alpha_{\overline{\theta}}} \gamma \\ \beta^{bc}_{\overline{\theta}} = u \\ A^{bc}_{\underline{\theta}} = -\frac{1}{2\alpha_{\underline{\theta}}} \left(\frac{(1-\rho)\alpha_{\underline{\theta}}}{\alpha_{\underline{\theta}} - \rho\alpha_{\overline{\theta}}} (u-\gamma) \right)^2 \\ A^{bc}_{\overline{\theta}} = -\frac{1}{2} \frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\left(1 - \frac{\alpha_{\overline{\theta}}}{\alpha_{\underline{\theta}}}\right) \frac{\left(\beta^{bc}_{\underline{\theta}} - \gamma\right)^2}{\alpha_{\underline{\theta}}} \end{cases} \tag{38}$$

$$\begin{cases} E(\pi^{bc}_{s\underline{\theta}}) = 0 \\ E(\pi^{bc}_{s\overline{\theta}}) = \frac{1}{2} \frac{\left(\beta^{bc}_{\underline{\theta}} - \gamma\right)^2}{\alpha_{\underline{\theta}}} \left(1 - \frac{\alpha_{\overline{\theta}}}{\alpha_{\underline{\theta}}}\right) \\ E(\pi^{bc}_b) = \frac{1}{2}\rho\left(\frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}} - E\left(1 - \frac{\alpha_{\overline{\theta}}}{\alpha_{\underline{\theta}}}\right)\right) + (1-\rho)\left(\left(u - \beta^{bc}_{\underline{\theta}}\right) \frac{\beta^{bc}_{\underline{\theta}} - \gamma}{\alpha_{\underline{\theta}}} + \frac{1}{2}E\right) - c_B \end{cases} \tag{39}$$

where $E = \frac{\left(\beta^{bc}_{\underline{\theta}} - \gamma\right)^2}{\alpha_{\underline{\theta}}}$.

Comparing Proposition 8 with Proposition 1, it is clear that the effort of the high-cost agent increases after the application of DTs, although the effort of the high-cost agent is still less than that of the high-cost agent when information is symmetric. That is, the principal's "channel loss" decreases after the application of DTs. This proof is given in Equation (40).

There is no doubt that, for the principal, if the DT application cost is not be considered (or if this cost is considered zero), the expected revenue of the principal must be increased. As the analytical solution is more complex, we prove this conclusion using the numerical solution in Section 6. We can also consider that this increase in the principal's expected revenue is precisely the upper limit of the cost of DT application. If the cost of applying DTs is higher than the increase in the expected benefit for the principal, the principal should not apply this technology that makes the information transparent.

$$e_{\underline{\theta}}^{bc} - e_{\underline{\theta}}^{tb} = \left(\frac{(1-\rho)\alpha_{\overline{\theta}}}{(1-\rho)\alpha_{\overline{\theta}} + \left(\alpha_{\underline{\theta}} - \alpha_{\overline{\theta}}\right)\rho} - \frac{(1-\rho)\alpha_{\underline{\theta}}}{(1-\rho)\alpha_{\underline{\theta}} + \rho\left(\alpha_{\underline{\theta}} - \alpha_{\overline{\theta}}\right)} \right) \left(\frac{u}{\alpha_{\underline{\theta}}} - \frac{\gamma}{\alpha_{\underline{\theta}}} \right) \frac{u}{\alpha_{\underline{\theta}}} \geq 0 \quad (40)$$

5.2. Incentive Contract Design When Considering Time Constraints of Principals after Applying DTs

Based on the analysis in Section 5.1, we further consider the menu of incentive contracts in supply chains when applying DTs in which the principals have time constraints.

(1) According to the previous analysis, the effort of the low-reliability agent increases after applying DTs, which means that, when the principal's time constraint satisfies $e' \leq e_{\underline{\theta}}^{bc}$, none of the principal's time constraints have any effect on the principal–agent model, and even if the principal's time constraint increases to $e_{\underline{\theta}}^{bc}$, the principal does not pay extra costs as a result. We believe that this is one of the benefits that DTs brings to commissioners.

(2) When the principal's time constraint is further increased to satisfy $e_{\underline{\theta}}^{bc} \leq e' \leq e_{\overline{\theta}}^{bc}$, the constraint impacts the agent's behavior. Under this condition, the principal–agent model of Equation (36) becomes

$$\begin{aligned} &E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{ \rho\left(ue_{\overline{\theta}} - A_{\overline{\theta}} - \beta_{\overline{\theta}} e_{\overline{\theta}}\right) + (1-\rho)\left(ue_{\underline{\theta}} - A_{\underline{\theta}} - \beta_{\underline{\theta}} e_{\underline{\theta}}\right) - c_B \right\} \\ &s.t. \begin{cases} \text{Constraints } (16, 35) \\ e_{\underline{\theta}}^{bc} \geq e' \end{cases} \end{aligned} \quad (41)$$

Proposition 9. *When the principal's effort constraint satisfies $e_{\underline{\theta}}^{bc} \leq e' \leq e_{\overline{\theta}}^{bc}$, the contract parameters given by the principal, the agent's effort, and the expected benefits for each agent are as follows (see Appendix F for the solution).*

$$\begin{cases} A_{\underline{\theta}}^{bc} = -\frac{1}{2}\alpha_{\underline{\theta}} e'^2 \\ A_{\overline{\theta}}^{bc} = -\frac{1}{2}\frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}e'^2\left(\alpha_{\underline{\theta}} - \alpha_{\overline{\theta}}\right) \\ \beta_{\underline{\theta}}^{bc} = \alpha_{\underline{\theta}} e' + \gamma \\ \beta_{\overline{\theta}}^{bc} = u \end{cases} \quad (42)$$

$$\begin{cases} e_{\underline{\theta}}^{bc} = e' \\ e_{\overline{\theta}}^{bc} = \frac{u-\gamma}{\alpha_{\overline{\theta}}} \\ E\left(\pi_{\underline{\theta}}^{bc}\right) = 0 \\ E\left(\pi_{\overline{\theta}}^{bc}\right) = \frac{1}{2}\left(\alpha_{\underline{\theta}} - \alpha_{\overline{\theta}}\right)e'^2 \\ E\left(\pi_b^{bc}\right) = \frac{1}{2}\rho\left(\frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}} - \left(\alpha_{\underline{\theta}} - \alpha_{\overline{\theta}}\right)e'^2\right) + (1-\rho)\left((u-\gamma)e' - \frac{1}{2}\alpha_{\underline{\theta}} e'^2\right) - c_B \end{cases} \quad (43)$$

Comparing Propositions 9 with 4, we found that the "information rent" paid by the principal to the low-cost agent is lower after applying DTs when $e_{\underline{\theta}}^{bc} \leq e' \leq e_{\overline{\theta}}^{bc}$ is satisfied.

This means that the application of DTs brings additional benefits to the client. At the same time, we can also consider that the reduced value of the "information rent" is exactly the upper limit of the application cost of DTs. When the application cost of DTs exceeds this value, we think that the client should not adopt this technology because it only makes the client suffer losses or the benefits brought by DTs are not enough to compensate for the costs.

(3) When the principal's effort constraint is further increased to satisfy $e' \geq \frac{u-\gamma}{\alpha_{\overline{\theta}}}$, the constraint impacts not only the behavior of the low–reliable agent but also that of

the high–reliable agent. Under this condition, the original principal–agent model of Equation (36) becomes

$$E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{ \rho\left(ue_{\overline{\theta}} - A_{\overline{\theta}} - \beta_{\overline{\theta}} e_{\overline{\theta}}\right) + (1-\rho)\left(ue_{\underline{\theta}} - A_{\underline{\theta}} - \beta_{\underline{\theta}} e_{\underline{\theta}}\right) - c_B \right\}$$
$$s.t. \begin{cases} \text{Constraints } (16,35) \\ e_{\underline{\theta}}^{bc} \geq e' \\ e_{\overline{\theta}}^{bc} \geq e' \end{cases} \tag{44}$$

Proposition 10. *When the principal's effort constraint satisfies* $e' \geq \frac{u-\gamma}{\alpha_{\overline{\theta}}}$*, the contract parameters given by the principal, the agent's effort, and the expected benefits for each party are as follows (see Appendix G for the solution).*

$$\begin{cases} A_{\overline{\theta}}^{bc} = \frac{1}{2}\alpha_{\underline{\theta}} e'^2 \left(1 - \frac{\alpha_{\overline{\theta}}}{\alpha_{\underline{\theta}}}\right) - \frac{1}{2}\alpha_{\overline{\theta}} e'^2 \\ A_{\underline{\theta}}^{bc} = -\frac{1}{2}\alpha_{\underline{\theta}} e'^2 \\ \beta_{\underline{\theta}}^{bc} = \alpha_{\underline{\theta}} e' + \gamma \\ \beta_{\overline{\theta}}^{bc} = \alpha_{\overline{\theta}} e' + \gamma \end{cases} \tag{45}$$

$$\begin{cases} e_{\underline{\theta}}^{bc} = e' \\ e_{\overline{\theta}}^{bc} = e' \end{cases} \tag{46}$$

$$\begin{cases} E\left(\pi_{\underline{\theta}}^{bc}\right) = 0 \\ E\left(\pi_{\overline{\theta}}^{bc}\right) = \frac{1}{2}\alpha_{\underline{\theta}} e'^2 \left(1 - \frac{\alpha_{\overline{\theta}}}{\alpha_{\underline{\theta}}}\right) \\ E(\pi_b^{bc}) = (u-\gamma)e' - \frac{1}{2}\alpha_{\underline{\theta}} e'^2 - c_B \end{cases} \tag{47}$$

Comparing Propositions 10 and 6, we can see that, after applying DTs, when the principal's effort constraint satisfies $e' \geq \frac{u-\gamma}{\alpha_{\overline{\theta}}}$, the principal's "information rent" paid to the low-cost agent decreases and this decrease in information rent is exactly the upper limit of the cost of applying DTs. In other words, when the application cost of DTs is higher than this, the principal should not apply the technology.

Based on the previous analysis, we can further conclude the followings.

Conclusion 1: In the supply chain, when there is a time constraint between the principal and the agent, the principal often pays the low-cost agent an additional "time cost" because of the constraint, which together with "information rent" and "channel loss" make up the total loss to the principal due to information asymmetry. This cost, together with the "information rent" and "channel loss", constitutes the total loss to the principal due to information asymmetry.

This finding extends the application of principal–agent theory to the field of KS in comparison with the studies of Nikoofal, M. E. and Gumus, M. [31] and of Wang, Q. K. and Shi, Q. [32]. Principals must recognize that higher incentive costs are necessary when considering the time properties of knowledge.

Conclusion 2: The application of DTs enhances the principal's expected revenue in three ways: (1) reduced "access loss"—after applying DTs, high-cost agents increase their efforts to make the principal's access loss lower; (2) reduced "information rent" for low-cost agents; and (3) reduced "time cost" for the principal. We know that a lower time constraint for the principal results in a higher additional "time cost" for the principal, but this "time cost" is reduced with the application of DTs. The sum of these three elements constitutes the value of DTs to the principal in the supply chain.

With this finding, we refined Treiblmaier's [27] research idea and demonstrated that the application of DTs change the principal–agent structure and principal–agent relationships with specific constraints (time constraints) of DTs can also increase the principal's expected profits.

Conclusion 3: Contrary to our intuition, in a time-constrained CBBM, the principal's time constraint does not necessarily result in additional expected profits for the agent. In this case, the expected gain for the high-cost agent remains at zero and the low-cost agent gains additional profit.

6. Example and Analysis

In order to illustrate the value of incentive contract design in a supply chain considering time constraints more intuitively and to make a comparative analysis, this paper used MATLAB to complete numerical simulations to verify and analyze the previous conclusions. In this section, specific assignments are calculated for each parameter in the model, assuming that the initial values of the parameters in question are $a_{\overline{\theta}} = [1, 6]$, $a_{\underline{\theta}} = 9$, $u = 20$, $\rho = 0.4, e' = [0, 5], \gamma = 5, c_B = 1$.

6.1. The Effect of Time Constraint on the Expected Returns of the Parties before Application DTs

As can be seen from Figures 2 and 3, the principal's expected revenue increases with their own time constraint and the agent's effort cost coefficient, mainly because the principal has to pay higher payments to the agent in order to incentivize the agent to participate in the supply chain when the agent's effort cost coefficient is higher. Similarly, when the principal's time requirement is high, the principal has to pay the low−cost agent a higher wage in order to incentivize the low−cost agent not to imitate the actions of the high−cost agent.

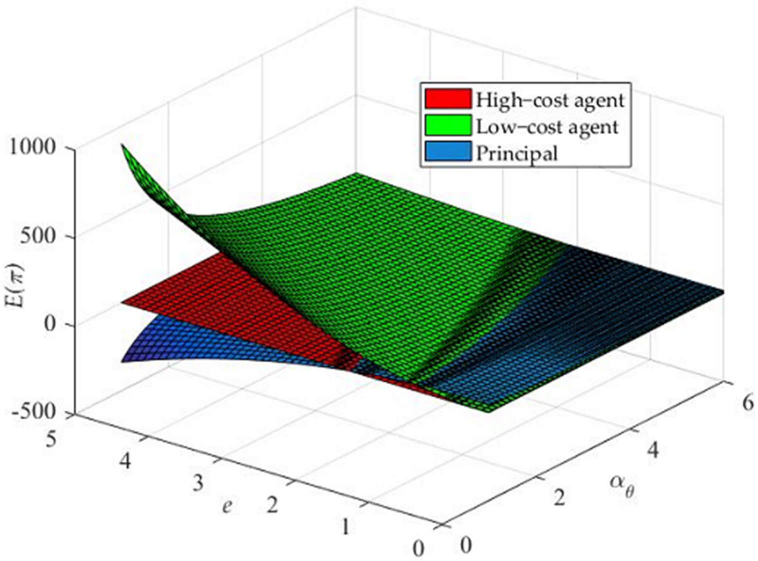

Figure 2. Effect of the effort level constraint and agent's effort cost coefficient on each party's expected return before applying DTs. In the figures, $E(\pi)$ represents the expected profit, e represents the degree of effort, α_θ represents the cost of the effort factor for a type θ agent, A represents the fixed payment in the incentive contract, and β represents the variable payment in the incentive contract, similarly hereinafter.

The high-cost agent is bound to receive a retained benefit and only a retained benefit regardless of the principal's time requirement and their own effort cost factor (this paper assumes that their retained benefit is zero).

For the low−cost agent, their expected payoff increases as the principal's time constraint increases and increases as the agent's effort cost factor increases. This is mainly because, when the principal's effort constraint is higher, the principal pays higher wages to the low−cost agent to motivate them not to imitate the high−cost agent's actions. When the effort cost coefficient of the high−cost agent is larger, the low−cost agent gains more because of the cost advantage.

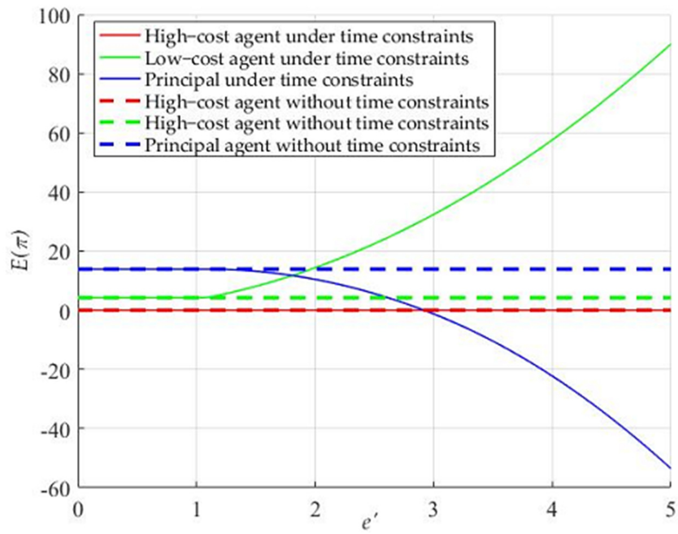

Figure 3. Effect of the pre-application of the effort constraint in DTs on the expected returns of each party ($\alpha_{\underline{\theta}} = 5, \alpha_{\overline{\theta}} = 9$).

As we can see in Figure 3, as in the previous analysis, in the case of information asymmetry, the principal suffers from an additional "time constraint cost" due to their own time constraint requirement in addition to the "information cost" loss, and the "time constraint cost" increases as the effort constraint increases. For the principal or manager, this "time constraint cost" is consistent with basic economic law.

6.2. The Effect of Time Constraints on the Expected Returns of the Parties before Application DTs

Through Figures 4 and 5, we can find that the incentive coefficient for the high−cost agent gradually increases when the principal's time constraint exceeds point A in the figure. When the effort constraint exceeds point B, not only will the incentive coefficient for the high−cost agent will increase but also the incentive coefficient for the low−cost agent will follow. For the high−cost agent, the principal can also reduce the fixed payment percentage in the contract to only receives the retained earnings. However, for the low−cost agent, the principal not only cannot reduce the fixed payments so that it only receives the retained benefits but must increase the fixed payments to provide an incentive not to imitate the actions of the high−cost agent.

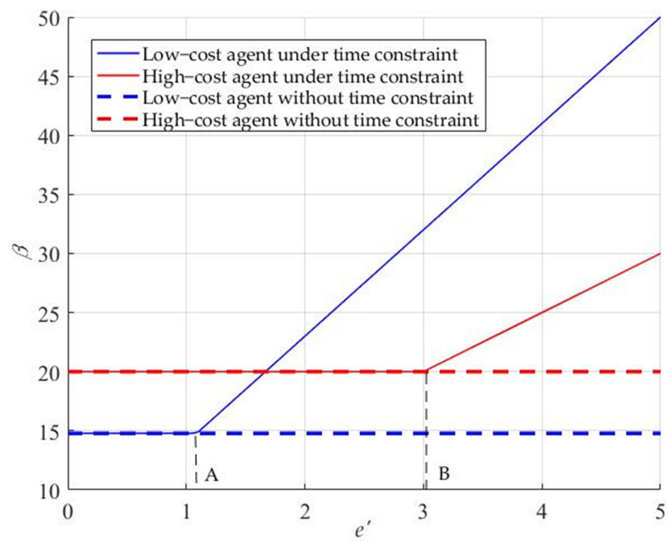

Figure 4. Effect of effort constraints on incentive coefficients in incentive contracts before the application of DTs.

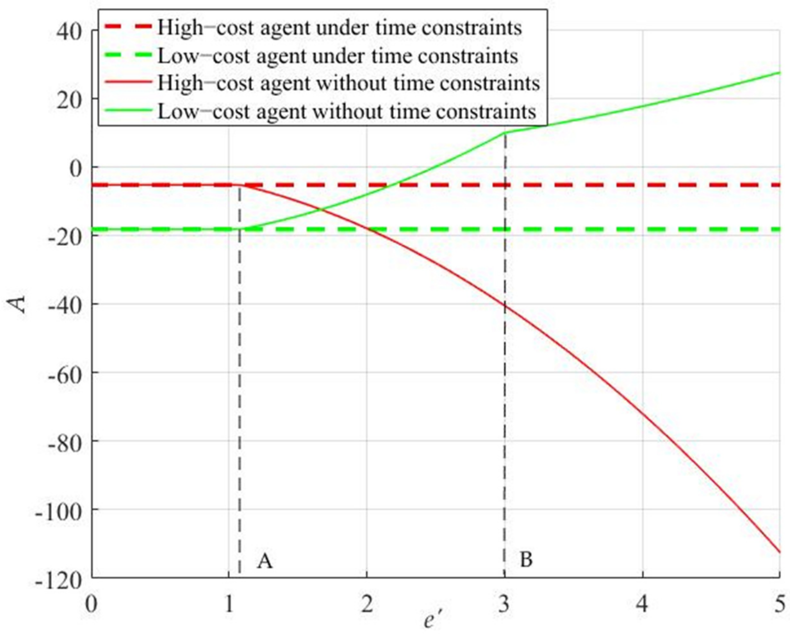

Figure 5. Effect of effort level constraints on fixed payments in incentive contracts before the application of DTs.

According to Figure 6, the principal's time constraint does not affect the agent's decision until point A. When the principal's time constraint determines the level of effort above point A, the high−cost agent's effort level decided is forcefully changed, but their level of effort is only equal to the principal's minimum requirement. When the principal's time constraint is higher than point B, the low−cost agent's decision is also affected, and again, their effort level is only equal to the principal's requirement.

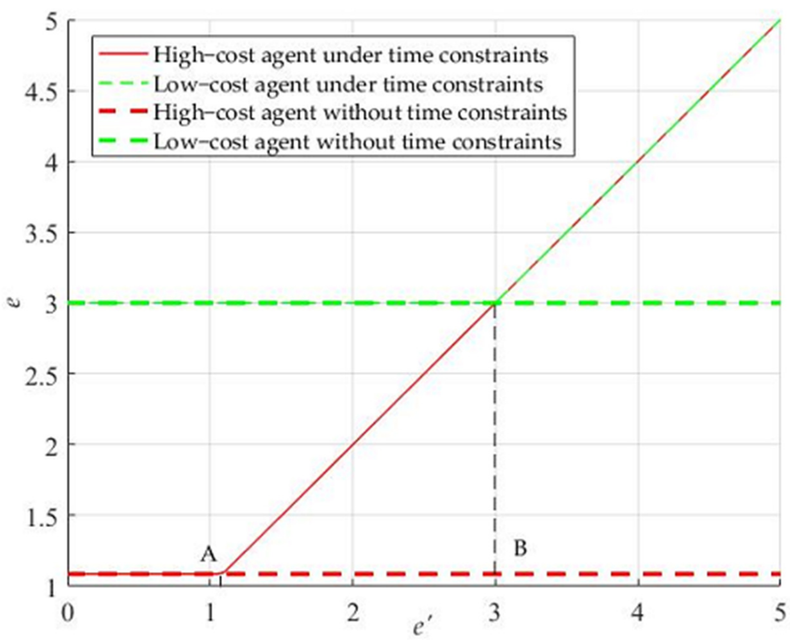

Figure 6. Degree of effort on the part of the agent before applying DTs.

6.3. Comparison of Commissioner Benefits before and after Applying DTs

According to Figures 7 and 8, after applying DTs, the principal's expected revenue increases while the expected revenue of the low−cost agent decreases and the expected revenue of the high−cost agent remains unchanged. According to Figure 8, before the application of DTs, the principal needs to pay the low−cost agent the "time constraint cost" when the effort constraint reaches point A, but after the application of DTs, this does not happen until point B is reached. Moreover, the principal pays less "time−constrained cost" for the same level of effort constraint after applying DTs. For the principal or manager, the application of DTs is profitable as long as the cost of applying DTs is lower than the difference between the principal's expected benefits before and after the application of DTs. It should also be noted that, the greater the principal's effort constraint, the greater the benefits of DTs to the principal. We can also consider that DTs reduce the "information cost" and reduce the "time constraint cost".

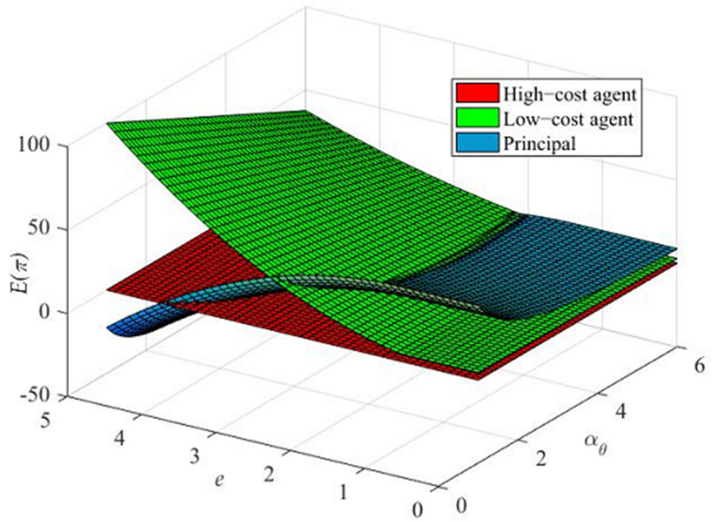

Figure 7. Comparison of the expected benefits of each party before and after the application of DTs.

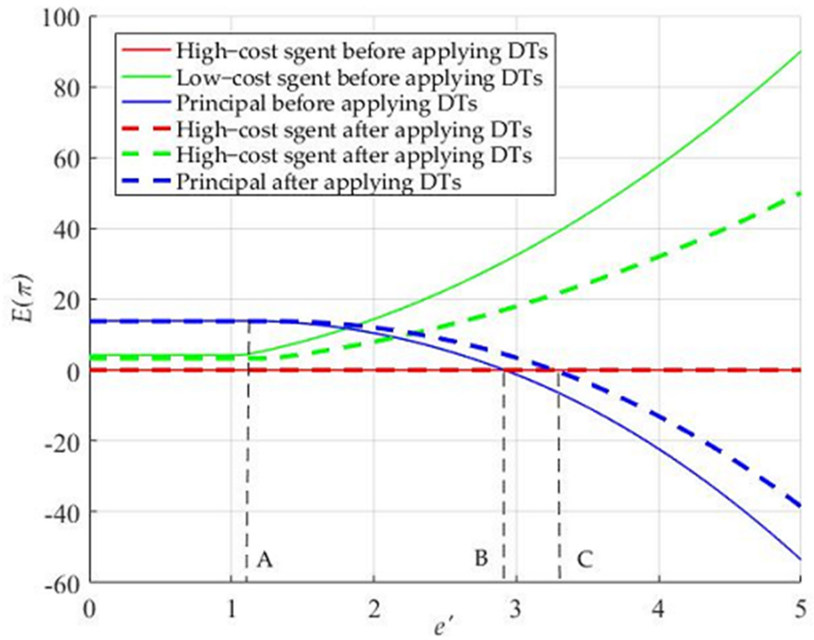

Figure 8. Comparison of the expected benefits of each party before and after the application of DTs.

6.4. The Impact of Applying DTs to the Menu of Incentive Contracts

According to Figures 9 and 10, it is clear that, with the application of DTs, the principal adjusts the incentive coefficient higher for high−cost agents, while reducing the fixed payment. This incentivizes them to increase their efforts while ensuring that their functions receive the retained benefits. Additionally, before applying DTs, the principal needs to further increase the incentive coefficient when the effort constraint reaches point A, and only after applying DTs, the effort constraint reaches the point A′, when the incentive coefficient needs to be conditionally high. For the low−cost agent, the principal's given incentive coefficient remains the same after applying DTs, while the fixed payment is reduced. This is where DTs bring benefits to the principal.

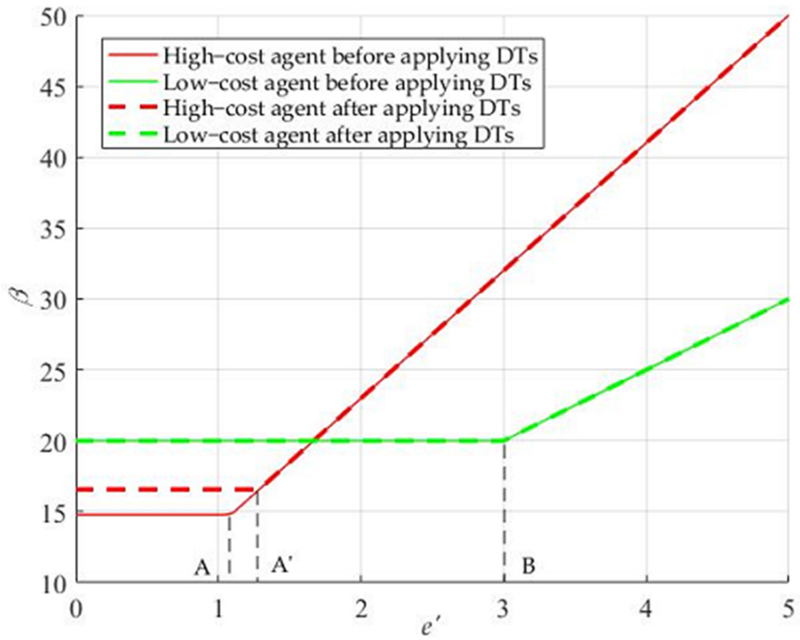

Figure 9. Comparison of the incentive coefficients given by the principal before and after the application of DTs.

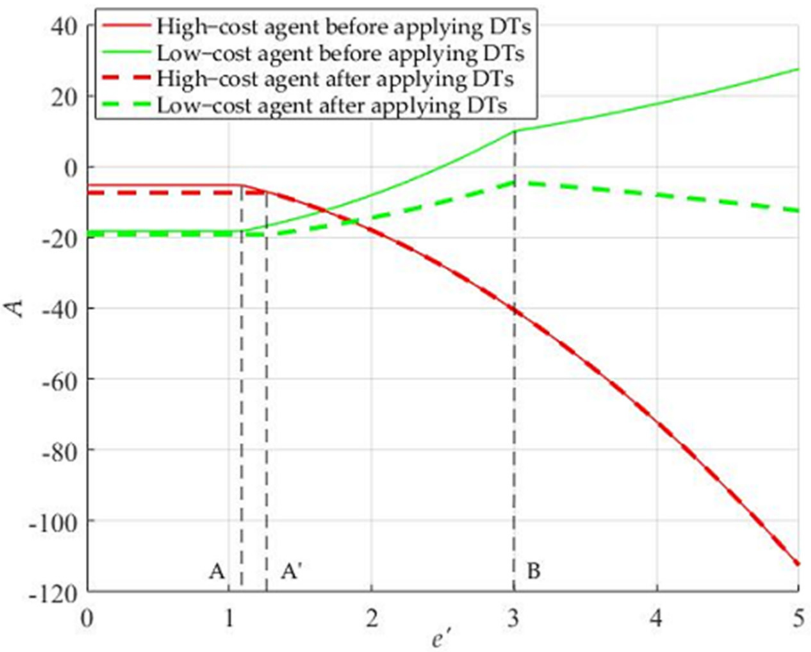

Figure 10. Comparison of fixed payments given by the commissioner before and after the application of DTs.

As we can see in Figure 11, the level of effort of the high-cost agent increases after the application of DTs (before the point A′) and follows the effort constraint after the point A′.

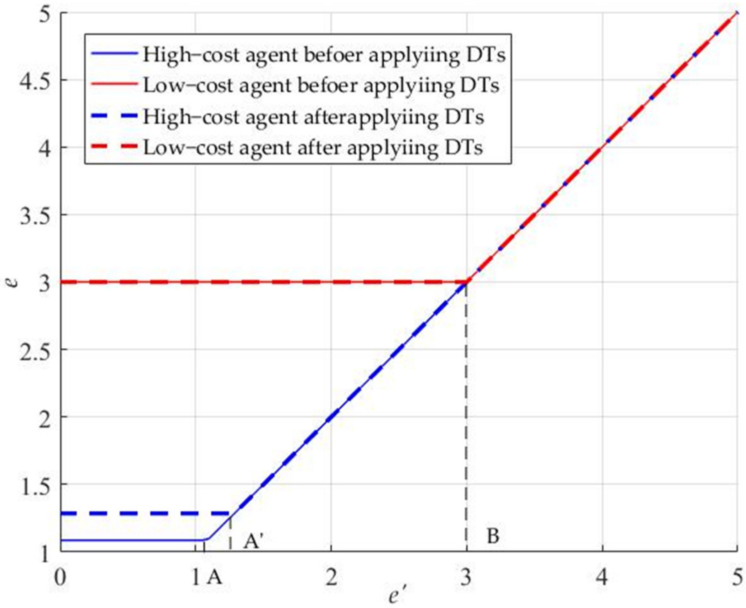

Figure 11. Comparison of agent effort before and after applying DTs.

The above analysis reveals that the incentive optimization model increases the effort of KS in the supply chain regardless of the time constraint of KS, but the expected benefit to the principal does not necessarily increase considering the application cost of DTs.

7. Conclusions

This paper investigates the design of incentive contracts by principals to motivate agents of different cost types to make optimal effort decisions conditional on the maximization of the principal's expected return in a multinational supply chain with time constraints for both principals and agents in the context of applying DTs to solve the information asymmetry problem. A principal–agent model is developed to analyze the expected revenue of the principal and the agent before and after the application of DTs and to design contract parameters for different types of agents. The optimal revenue, contract parameters, and optimal effort of both parties before and after the application of DTs are solved.

The findings of this study answer but are not limited to the questions posed in the introduction: (1) Compared with the study of Nikoofal, M. E. and Gumus, M. [31], in a CBBM with a KS time constraint, the principal's expected revenue may be lower and the low-cost agent benefits as a result, but the high-cost agent does not gain additional revenue due to the constraint. (2) Due to this constraint, the principal gives a higher incentive factor to motivate the agent to increase effort, while the principal also increases the fixed payment component of the low-cost contract to incentivize the low-cost agent not to imitate the high-cost agent's behavior. (3) Compared with the studies of Chen, W. D. and Li, L. M. [70] and of Nikoofal, M. E. and Gumus, M. [31], when the principal has a time constraint, in addition to suffering from the "information cost" and "channel loss" due to information asymmetry, the principal also suffers from loss of the "time constraint cost" due to the time constraint. (4) Finally, after applying DTs, the high-cost agent increases their effort but still receives and only receives retention benefits. In contrast, the low-cost agent's effort remains unchanged, but their "information rent" and "time constraint cost" are reduced to some extent. The low-cost agent's effort remains the same, but their "information rent" and "time-constrained cost" decrease, i.e., their expected benefits are lower but still higher than their retained benefits.

Based on the research analysis conducted in this paper, some corresponding managerial insights are as follows:

From the principal's perspective, the parameters of the incentive contract need to be appropriately increased to motivate the agent to share knowledge more diligently due to the time property of knowledge. When DTs are used to improve the efficiency of KS, the difference between the cost of DTs and the corresponding benefits of monitoring is an issue that needs to be considered.

From the agent's perspective, the time attribute (cost) of knowledge needs to be considered in addition to the cost of KS effort. At the same time, the application of DTs by the principal to improve information asymmetry can reduce the expected benefits for the agent. Therefore, the agent should pay more attention to the behavior of KS and increase their own benefits by reducing the cost of KS.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Model Solution When Disregarding Time Constraints for the Information Asymmetry Scenario

According to Equations (7) and (10), we obtain the following:

$$\begin{cases} e^{sb}_{\underline{\theta}} = \frac{\beta_{\underline{\theta}}}{\alpha_{\underline{\theta}}} \\ e^{sb}_{\overline{\theta}} = \frac{\beta_{\overline{\theta}}}{\alpha_{\overline{\theta}}} \end{cases}, \begin{cases} \hat{e}^{sb}_{\underline{\theta}} = \frac{\beta_{\overline{\theta}}}{\alpha_{\underline{\theta}}} \\ \hat{e}^{sb}_{\overline{\theta}} = \frac{\beta_{\underline{\theta}}}{\alpha_{\overline{\theta}}} \end{cases} \tag{A1}$$

$$\begin{cases} \hat{e}^{sb}_{\underline{\theta}} = \frac{\beta_{\overline{\theta}}}{\alpha_{\underline{\theta}}} \\ \hat{e}^{sb}_{\overline{\theta}} = \frac{\beta_{\underline{\theta}}}{\alpha_{\overline{\theta}}} \end{cases} \tag{A2}$$

Substituting Equations (A1) and (A2) into Equations (8), (9) and (11), we obtain the following:

$$\begin{aligned} & E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{\rho\left(u\frac{\beta_{\overline{\theta}}}{\alpha_{\overline{\theta}}} - A_{\overline{\theta}} - \beta_{\overline{\theta}}\frac{\beta_{\overline{\theta}}}{\alpha_{\overline{\theta}}}\right) + (1-\rho)\left(u\frac{\beta_{\underline{\theta}}}{\alpha_{\underline{\theta}}} - A_{\underline{\theta}} - \beta_{\underline{\theta}}\frac{\beta_{\underline{\theta}}}{\alpha_{\underline{\theta}}}\right)\right\} \\ & s.t. \begin{cases} A_{\underline{\theta}} + \frac{1}{2}\frac{\beta_{\underline{\theta}}^2}{\alpha_{\underline{\theta}}} \geq 0(1) \\ A_{\overline{\theta}} + \frac{1}{2}\frac{\beta_{\overline{\theta}}^2}{\alpha_{\overline{\theta}}} \geq 0(2) \\ A_{\underline{\theta}} + \frac{1}{2}\frac{\beta_{\underline{\theta}}^2}{\alpha_{\underline{\theta}}} \geq A_{\overline{\theta}} + \frac{1}{2}\frac{\beta_{\overline{\theta}}^2}{\alpha_{\underline{\theta}}}(3) \\ A_{\overline{\theta}} + \frac{1}{2}\frac{\beta_{\overline{\theta}}^2}{\alpha_{\overline{\theta}}} \geq A_{\underline{\theta}} + \frac{1}{2}\frac{\beta_{\underline{\theta}}^2}{\alpha_{\overline{\theta}}}(4) \end{cases} \end{aligned} \tag{A3}$$

In Equation (A3), constraint (2) clearly holds according to constraints (1) and (4), while we know that, in reality, it is often the case that the low-cost agent imitates the behavior of the high-cost agent. Therefore, we assume that constraints (1) and (4) are taut. Of course, later, we need to verify the correctness of the assumption:

$$\begin{aligned} & E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{\rho\left(u\frac{\beta_{\overline{\theta}}}{\alpha_{\overline{\theta}}} - A_{\overline{\theta}} - \beta_{\overline{\theta}}\frac{\beta_{\overline{\theta}}}{\alpha_{\overline{\theta}}}\right) + (1-\rho)\left(u\frac{\beta_{\underline{\theta}}}{\alpha_{\underline{\theta}}} - A_{\underline{\theta}} - \beta_{\underline{\theta}}\frac{\beta_{\underline{\theta}}}{\alpha_{\underline{\theta}}}\right)\right\} \\ & s.t. \begin{cases} A_{\underline{\theta}} = -\frac{1}{2}\frac{\beta_{\underline{\theta}}^2}{\alpha_{\underline{\theta}}}(1) \\ A_{\overline{\theta}} = -\frac{1}{2}\frac{\beta_{\overline{\theta}}^2}{\alpha_{\overline{\theta}}} - \frac{1}{2}\frac{\beta_{\underline{\theta}}^2}{\alpha_{\underline{\theta}}} + \frac{1}{2}\frac{\beta_{\underline{\theta}}^2}{\alpha_{\overline{\theta}}}(2) \end{cases} \end{aligned} \tag{A4}$$

In (A4), substituting constraints (1) and (2) into the objective function, we obtain the following:

$$E(\pi_b) = \max_{(\beta_{\underline{\theta}},\beta_{\overline{\theta}})}\left\{\rho\left(u\frac{\beta_{\overline{\theta}}}{\alpha_{\overline{\theta}}} - \frac{1}{2}\frac{\beta_{\overline{\theta}}{}^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\frac{\beta_{\underline{\theta}}{}^2}{\alpha_{\underline{\theta}}} - \frac{1}{2}\frac{\beta_{\underline{\theta}}{}^2}{\alpha_{\overline{\theta}}}\right) + (1-\rho)\left(u\frac{\beta_{\underline{\theta}}}{\alpha_{\underline{\theta}}} - \frac{1}{2}\frac{\beta_{\underline{\theta}}{}^2}{\alpha_{\underline{\theta}}}\right)\right\} \tag{A5}$$

According to (A5), the first- and second-order derivatives of the derivative of $E(\pi_b)$ with respect to $\beta_{\underline{\theta}}, \beta_{\overline{\theta}}$ are

$$\begin{cases}\begin{cases}\frac{\partial E(\pi_b)}{\partial \beta_{\underline{\theta}}} = \rho\left(\frac{\beta_{\underline{\theta}}}{\alpha_{\underline{\theta}}} - \frac{\beta_{\underline{\theta}}}{\alpha_{\overline{\theta}}}\right) + (1-\rho)\left(\frac{u}{\alpha_{\underline{\theta}}} - \frac{\beta_{\underline{\theta}}}{\alpha_{\underline{\theta}}}\right) \\ \frac{\partial E(\pi_b)}{\partial \beta_{\overline{\theta}}} = \rho\left(\frac{u}{\alpha_{\overline{\theta}}} - \frac{\beta_{\overline{\theta}}}{\alpha_{\overline{\theta}}}\right)\end{cases} \\ \begin{cases}\frac{\partial^2 E(\pi_b)}{\partial \beta_{\underline{\theta}}{}^2} = \rho\left(\frac{1}{\alpha_{\underline{\theta}}} - \frac{1}{\alpha_{\overline{\theta}}}\right) + (1-\rho)\left(-\frac{1}{\alpha_{\underline{\theta}}}\right) \\ \frac{\partial^2 E(\pi_b)}{\partial \beta_{\underline{\theta}}\partial \beta_{\overline{\theta}}} = 0 \\ \frac{\partial^2 E(\pi_b)}{\partial \beta_{\overline{\theta}}\partial \beta_{\underline{\theta}}} = 0 \\ \frac{\partial^2 E(\pi_b)}{\partial \beta_{\overline{\theta}}{}^2} = -\rho\frac{1}{\alpha_{\overline{\theta}}}\end{cases}\end{cases} \tag{A6}$$

The corresponding Hessian matrix H_1 is

$$H_1 = \begin{bmatrix} \frac{\partial^2 E(\pi_b)}{\partial \beta_{\underline{\theta}}{}^2} & \frac{\partial^2 E(\pi_b)}{\partial \beta_{\underline{\theta}}\partial \beta_{\overline{\theta}}} \\ \frac{\partial^2 E(\pi_b)}{\partial \beta_{\overline{\theta}}\partial \beta_{\underline{\theta}}} & \frac{\partial^2 E(\pi_b)}{\partial \beta_{\overline{\theta}}{}^2} \end{bmatrix} \tag{A7}$$

According to Equation (A7), it is known that the Hessian matrix H_1 is negative definite, and at this time, there is an extreme value of the objective function. According to the first order condition, the following is obtained:

$$\begin{cases}\begin{cases}\beta^{sb}_{\underline{\theta}} = \frac{-u\alpha_{\overline{\theta}}(1-\rho)}{(2\rho-1)\alpha_{\overline{\theta}}-\rho\alpha_{\underline{\theta}}} = \frac{\alpha_{\overline{\theta}}(1-\rho)}{\alpha_{\overline{\theta}}(1-\rho)+\rho\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)}u \\ \beta^{sb}_{\overline{\theta}} = u\end{cases} \\ \begin{cases}A^{sb}_{\underline{\theta}} = -\frac{1}{2}\frac{\beta^{sb2}_{\underline{\theta}}}{\alpha_{\underline{\theta}}} \\ A^{sb}_{\overline{\theta}} = -\frac{1}{2}\frac{u^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\beta^{sb2}_{\underline{\theta}}\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right)\end{cases}\end{cases} \tag{A8}$$

Substituting Equation (A8) into Equation (7), we obtain the optimal level of effort of the agent:

$$\begin{cases} e^{sb}_{\underline{\theta}} = \frac{\beta^{sb}_{\underline{\theta}}}{\alpha_{\underline{\theta}}} = \frac{\alpha_{\overline{\theta}}(1-\rho)}{\alpha_{\overline{\theta}}(1-\rho)+\rho\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)}\frac{u}{\alpha_{\underline{\theta}}} \\ e^{sb}_{\overline{\theta}} = \frac{\beta^{sb}_{\overline{\theta}}}{\alpha_{\overline{\theta}}} = \frac{u}{\alpha_{\overline{\theta}}} \end{cases} \tag{A9}$$

where $\frac{\alpha_{\overline{\theta}}(1-\rho)}{\alpha_{\overline{\theta}}(1-\rho)+\rho\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)} \leq 1$.

Substituting Equations (A8) and (A9) into the original constraint verification, we obtain the following

$$\begin{cases} A_{\overline{\theta}} + \frac{1}{2}\frac{\beta_{\overline{\theta}}{}^2}{\alpha_{\overline{\theta}}} = \frac{1}{2}\beta^{sb2}_{\underline{\theta}}\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right) \geq 0, \text{The hypothesis holds.} \\ A_{\underline{\theta}} + \frac{1}{2}\frac{\beta_{\underline{\theta}}{}^2}{\alpha_{\underline{\theta}}} = -\frac{1}{2}\frac{\beta_{\underline{\theta}}{}^2}{\alpha_{\underline{\theta}}} + \frac{1}{2}\frac{\beta_{\underline{\theta}}{}^2}{\alpha_{\underline{\theta}}} = 0 \geq \frac{1}{2}\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right)\left(\beta_{\underline{\theta}}{}^2 - \beta_{\overline{\theta}}{}^2\right), \text{The hypothesis holds} \end{cases} \tag{A10}$$

According to the verification of Equation (A10), it is clear that the assumption above holds, that is, the current optimal solution is the optimal solution of the original principal–agent model.

Substituting Equations (A9) and (A10) into the original function, we obtain the benefits for the agent and the principal, respectively, as follows:

The expected return for the agent is

$$\begin{cases} E(\pi^{sb}_{s\underline{\theta}}) = -\frac{1}{2}\frac{\beta^{sb2}_{\underline{\theta}}}{\alpha_{\underline{\theta}}} + \frac{1}{2}\frac{\beta_{\underline{\theta}}{}^2}{\alpha_{\underline{\theta}}} = 0 \\ E(\pi^{sb}_{s\overline{\theta}}) = \frac{1}{2}\left(\frac{\alpha_{\overline{\theta}}(1-\rho)}{\alpha_{\overline{\theta}}(1-\rho)+\rho\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)}u\right)^2\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right) \geq 0 \end{cases} \tag{A11}$$

The expected profit of the commissioning party is

$$E(\pi^{sb}_b) = \rho\left(\frac{1}{2}\frac{u^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\beta^{sb2}_{\underline{\theta}}\left(\frac{1}{\alpha_{\underline{\theta}}} - \frac{1}{\alpha_{\overline{\theta}}}\right)\right) + (1-\rho)\left(u\frac{\beta^{sb}_{\underline{\theta}}}{\alpha_{\underline{\theta}}} - \frac{1}{2}\frac{\beta^{sb2}_{\underline{\theta}}}{\alpha_{\underline{\theta}}}\right) \tag{A12}$$

where $\frac{1}{2}\frac{u^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\beta^{sb2}_{\underline{\theta}}\left(\frac{1}{\alpha_{\underline{\theta}}} - \frac{1}{\alpha_{\overline{\theta}}}\right) \leq \frac{1}{2}\frac{u^2}{\alpha_{\overline{\theta}}}$ and $u\frac{\beta^{sb}_{\underline{\theta}}}{\alpha_{\underline{\theta}}} - \frac{1}{2}\frac{\beta^{sb2}_{\underline{\theta}}}{\alpha_{\underline{\theta}}} \leq \frac{1}{2}\frac{u^2}{\alpha_{\underline{\theta}}}$.

Appendix B. Model Solution When Considering the Presence of Time Constraints of the Agents

Equation (20) can be rewritten as

$$E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{\rho\left(ue_{\overline{\theta}} - A_{\overline{\theta}} - \beta_{\overline{\theta}}e_{\overline{\theta}}\right) + (1-\rho)\left(ue_{\underline{\theta}} - A_{\underline{\theta}} - \beta_{\underline{\theta}}e_{\underline{\theta}}\right)\right\}$$
$$s.t.\begin{cases} e^{tb}_{\theta} = \underset{e_\theta}{\operatorname{argmax}}\left\{A_\theta + \beta_\theta e_\theta - \frac{1}{2}\alpha_\theta e_\theta{}^2 - \gamma e_\theta\right\}, \theta \in \left\{\overline{\theta}, \underline{\theta}\right\}(IC-1,2) \\ A_\theta + \beta_\theta e_\theta - \frac{1}{2}\alpha_\theta e_\theta{}^2 - \gamma e_\theta \geq 0, \theta \in \left\{\overline{\theta}, \underline{\theta}\right\}(IR-1,2) \\ A_{\underline{\theta}} + \beta_{\underline{\theta}}e_{\underline{\theta}} - \frac{1}{2}\alpha_{\underline{\theta}}e_{\underline{\theta}}{}^2 - \gamma e_{\underline{\theta}} \geq A_{\overline{\theta}} + \beta_{\overline{\theta}}\hat{e}^{tb}_{\underline{\theta}} - \frac{1}{2}\alpha_{\underline{\theta}}\hat{e}^{tb2}_{\underline{\theta}} - \gamma\hat{e}^{tb}_{\underline{\theta}}(IC-3) \\ A_{\overline{\theta}} + \beta_{\overline{\theta}}e_{\overline{\theta}} - \frac{1}{2}\alpha_{\overline{\theta}}e_{\overline{\theta}}{}^2 - \gamma e_{\overline{\theta}} \geq A_{\underline{\theta}} + \beta_{\underline{\theta}}\hat{e}^{tb}_{\overline{\theta}} - \frac{1}{2}\alpha_{\overline{\theta}}\hat{e}^{tb2}_{\overline{\theta}} - \gamma\hat{e}^{tb}_{\overline{\theta}}(IC-4) \\ \hat{e}^{tb}_{\overline{\theta}} = \underset{e_{\overline{\theta}}}{\operatorname{argmax}}\left\{A_{\underline{\theta}} + \beta_{\underline{\theta}}e_{\overline{\theta}} - \frac{1}{2}\alpha_{\overline{\theta}}e_{\overline{\theta}}{}^2 - \gamma e_{\overline{\theta}}\right\}(IR-3) \\ \hat{e}^{tb}_{\underline{\theta}} = \underset{e_{\underline{\theta}}}{\operatorname{argmax}}\left\{A_{\overline{\theta}} + \beta_{\overline{\theta}}e_{\underline{\theta}} - \frac{1}{2}\alpha_{\underline{\theta}}e_{\underline{\theta}}{}^2 - \gamma e_{\underline{\theta}}\right\}(IR-4) \end{cases} \tag{A13}$$

In Equation (A13), based on the incentive compatibility constraint and the individual rationality constraint, we obtain the following:

$$E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{\rho\left(\left(u-\beta_{\overline{\theta}}\right)\frac{(\beta_{\overline{\theta}}-\gamma)}{\alpha_{\overline{\theta}}} - A_{\overline{\theta}}\right) + (1-\rho)\left(\left(u-\beta_{\underline{\theta}}\right)\frac{(\beta_{\underline{\theta}}-\gamma)}{\alpha_{\underline{\theta}}} - A_{\underline{\theta}}\right)\right\}$$
$$s.t.\begin{cases} A_{\underline{\theta}} + \frac{1}{2}\frac{(\beta_{\underline{\theta}}-\gamma)^2}{\alpha_{\underline{\theta}}} \geq 0(1) \\ A_{\overline{\theta}} + \frac{1}{2}\frac{(\beta_{\overline{\theta}}-\gamma)^2}{\alpha_{\overline{\theta}}} \geq 0(2) \\ A_{\underline{\theta}} + \frac{1}{2}\frac{(\beta_{\underline{\theta}}-\gamma)^2}{\alpha_{\underline{\theta}}} \geq A_{\overline{\theta}} + \frac{1}{2}\frac{(\beta_{\overline{\theta}}-\gamma)^2}{\alpha_{\underline{\theta}}}(3) \\ A_{\overline{\theta}} + \frac{1}{2}\frac{(\beta_{\overline{\theta}}-\gamma)^2}{\alpha_{\overline{\theta}}} \geq A_{\underline{\theta}} + \frac{1}{2}\frac{(\beta_{\underline{\theta}}-\gamma)^2}{\alpha_{\overline{\theta}}}(4) \end{cases} \tag{A14}$$

In Equation (A14), constraint (2) clearly holds according to constraints (1) and (4), while we know that, in reality, it is often the case that the low-cost agent imitates the high-cost agent. Therefore, we assume that constraints (1) and (4) are tight. Of course, later, we need to verify the correctness of this assumption; at this point, in Equation (A14), constraints (1) and (4) take equal signs (boundary conditions) and are substituted into the objective function as follows:

$$E(\pi_b) = \max_{(\beta_{\underline{\theta}},\beta_{\overline{\theta}})}\left\{\begin{array}{l} \rho\left(\left(u-\beta_{\overline{\theta}}\right)\frac{(\beta_{\overline{\theta}}-\gamma)}{\alpha_{\overline{\theta}}} + \frac{1}{2}\frac{(\beta_{\overline{\theta}}-\gamma)^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\frac{(\beta_{\underline{\theta}}-\gamma)^2}{\alpha_{\underline{\theta}}} - \frac{1}{2}\frac{(\beta_{\underline{\theta}}-\gamma)^2}{\alpha_{\overline{\theta}}}\right) \\ +(1-\rho)\left(\left(u-\beta_{\underline{\theta}}\right)\frac{(\beta_{\underline{\theta}}-\gamma)}{\alpha_{\underline{\theta}}} + \frac{1}{2}\frac{(\beta_{\underline{\theta}}-\gamma)^2}{\alpha_{\underline{\theta}}}\right) \end{array}\right\} \tag{A15}$$

According to Equation (A15), the first- and second-order derivatives of $E(\pi_b)$ with respect to $\beta_{\underline{\theta}}, \beta_{\overline{\theta}}$ are

$$\begin{cases} \frac{\partial E(\pi_b)}{\partial \beta_{\underline{\theta}}} = \rho\left(\frac{\left(\beta_{\underline{\theta}}-\gamma\right)}{\alpha_{\underline{\theta}}} - \frac{\left(\beta_{\underline{\theta}}-\gamma\right)}{\alpha_{\overline{\theta}}}\right) + (1-\rho)\frac{\left(u-\beta_{\underline{\theta}}\right)}{\alpha_{\underline{\theta}}} \\ \frac{\partial E(\pi_b)}{\partial \beta_{\overline{\theta}}} = \rho\frac{\left(u-\beta_{\overline{\theta}}\right)}{\alpha_{\overline{\theta}}} \end{cases}$$
$$\begin{cases} \frac{\partial^2 E(\pi_b)}{\partial {\beta_{\underline{\theta}}}^2} = \rho\left(\frac{1}{\alpha_{\underline{\theta}}} - \frac{1}{\alpha_{\overline{\theta}}}\right) - (1-\rho)\frac{1}{\alpha_{\underline{\theta}}} \\ \frac{\partial^2 E(\pi_b)}{\partial \beta_{\underline{\theta}} \partial \beta_{\overline{\theta}}} = 0 \\ \frac{\partial^2 E(\pi_b)}{\partial \beta_{\overline{\theta}} \partial \beta_{\underline{\theta}}} = 0 \\ \frac{\partial^2 E(\pi_b)}{\partial {\beta_{\overline{\theta}}}^2} = -\rho\frac{1}{\alpha_{\overline{\theta}}} \end{cases} \tag{A16}$$

Obviously, the Hessian matrix determined by the second-order partial derivatives in Equation (A16) is negative definite and the function has a maximal value, which is obtained according to the first-order condition.

$$\begin{cases} \beta^{tb}_{\underline{\theta}} = \frac{(1-\rho)u\alpha_{\overline{\theta}} + \rho\gamma\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)}{\alpha_{\overline{\theta}}(1-\rho)+\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)\rho} \\ \beta^{tb}_{\overline{\theta}} = u \end{cases}$$
$$\begin{cases} A^{tb}_{\underline{\theta}} = -\frac{1}{2}\frac{\left(\beta^{tb}_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\underline{\theta}}} \\ A^{tb}_{\overline{\theta}} = -\frac{1}{2}\frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}} - \frac{1}{2}\frac{\left(\beta^{tb}_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\underline{\theta}}} + \frac{1}{2}\frac{\left(\beta^{tb}_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}} \end{cases} \tag{A17}$$

Substituting Equation (A17) into the individual rationality constraint yields that the agent's optimal level of effort is

$$\begin{cases} e^{tb}_{\underline{\theta}} = \frac{\beta^{tb}_{\underline{\theta}}-\gamma}{\alpha_{\underline{\theta}}} = \frac{(1-\rho)\alpha_{\overline{\theta}}}{\alpha_{\overline{\theta}}(1-\rho)+\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)\rho}\frac{u-\gamma}{\alpha_{\underline{\theta}}} \\ e^{tb}_{\overline{\theta}} = \frac{\beta^{tb}_{\overline{\theta}}-\gamma}{\alpha_{\overline{\theta}}} = \frac{u-\gamma}{\alpha_{\overline{\theta}}} \end{cases} \tag{A18}$$

Substituting Equations (A17) and (A18) into the original constraint verification, we obtain

$$\begin{cases} A^{tb}_{\overline{\theta}} + \frac{1}{2}\frac{\left(\beta^{tb}_{\overline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}} = \frac{1}{2}\frac{\left(\beta^{tb}_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}}\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right) \geq 0, \text{The hypothesis holds} \\ A^{tb}_{\underline{\theta}} + \frac{1}{2}\frac{\left(\beta^{tb}_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\underline{\theta}}} = 0 \geq \frac{1}{2}\left((u-\gamma)^2 - \left(\beta^{tb}_{\underline{\theta}}-\gamma\right)^2\right)\left(\frac{1}{\alpha_{\underline{\theta}}} - \frac{1}{\alpha_{\overline{\theta}}}\right), \text{The hypothesis holds} \end{cases} \tag{A19}$$

According to the verification of Equation (A19), it is clear that the assumption above holds, that is, the current optimal solution is the optimal solution of the original principal–agent model.

Substituting Equations (A17) and (A18) into the original function, we can obtain the expected profits of the agent and the principal, respectively, as follows:

The expected profit of the agent is

$$\begin{cases} E\left(\pi^{tb}_{s\underline{\theta}}\right) = 0 \\ E\left(\pi^{tb}_{s\overline{\theta}}\right) = \frac{1}{2}\left(\frac{(1-\rho)\alpha_{\overline{\theta}}}{\alpha_{\overline{\theta}}(1-\rho)+\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)\rho}u - \left(\frac{\alpha_{\overline{\theta}}(1-\rho)}{\alpha_{\overline{\theta}}(1-\rho)+\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)\rho}\right)\gamma\right)^2\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right) \geq 0 \end{cases} \tag{A20}$$

The expected profit of the commissioning party is

$$E\left(\pi^{tb}_{b}\right) = \rho\left(\frac{1}{2}\frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\left(\beta^{tb}_{\underline{\theta}}-\gamma\right)^2\left(\frac{1}{\alpha_{\underline{\theta}}} - \frac{1}{\alpha_{\overline{\theta}}}\right)\right) + (1-\rho)\left(\left(u-\beta^{tb}_{\underline{\theta}}\right)\frac{\left(\beta^{tb}_{\underline{\theta}}-\gamma\right)}{\alpha_{\underline{\theta}}} + \frac{1}{2}\frac{\left(\beta^{tb}_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\underline{\theta}}}\right) \tag{A21}$$

Appendix C. Solving the Model When the Effort Determined by the Principal's Time Constraint under the Information Asymmetry Scenario Satisfies $e_{\underline{\theta}}^{tb} \leq e^{'} \leq e_{\overline{\theta}}^{tb}$

Equation (25) can be rewritten as

$$E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{\rho\left(ue_{\overline{\theta}} - A_{\overline{\theta}} - \beta_{\overline{\theta}}e_{\overline{\theta}}\right) + (1-\rho)\left(ue_{\underline{\theta}} - A_{\underline{\theta}} - \beta_{\underline{\theta}}e_{\underline{\theta}}\right)\right\}$$
$$s.t.\begin{cases} e_{\overline{\theta}}^{lb} = \underset{e_{\overline{\theta}}}{\operatorname{argmax}}\left\{A_{\overline{\theta}} + \beta_{\overline{\theta}}e_{\overline{\theta}} - \frac{1}{2}\alpha_{\overline{\theta}}e_{\overline{\theta}}{}^2 - \gamma e_{\overline{\theta}}\right\} \\ e_{\underline{\theta}}^{lb} = \underset{e_{\underline{\theta}}}{\operatorname{argmax}}\left\{A_{\underline{\theta}} + \beta_{\underline{\theta}}e_{\underline{\theta}} - \frac{1}{2}\alpha_{\underline{\theta}}e_{\underline{\theta}}{}^2 - \gamma e_{\underline{\theta}}\right\} \\ A_\theta + \beta_\theta e_\theta - \frac{1}{2}\alpha_\theta e_\theta{}^2 - \gamma e_\theta \geq 0, \theta \in \left\{\overline{\theta}, \underline{\theta}\right\} \\ A_{\underline{\theta}} + \beta_{\underline{\theta}}e_{\underline{\theta}}^{lb} - \frac{1}{2}\alpha_{\underline{\theta}}e_{\underline{\theta}}^{lb2} - \gamma e_{\underline{\theta}}^{lb} \geq A_{\overline{\theta}} + \beta_{\overline{\theta}}\hat{e}_{\underline{\theta}}^{lb} - \frac{1}{2}\alpha_{\underline{\theta}}\hat{e}_{\underline{\theta}}^{lb2} - \gamma\hat{e}_{\underline{\theta}}^{lb} \\ A_{\overline{\theta}} + \beta_{\overline{\theta}}e_{\overline{\theta}}^{\overline{l}b} - \frac{1}{2}\alpha_{\overline{\theta}}e_{\overline{\theta}}^{\overline{l}b2} - \gamma e_{\overline{\theta}}^{\overline{l}b} \geq A_{\underline{\theta}} + \beta_{\underline{\theta}}\hat{e}_{\overline{\theta}}^{\overline{l}b} - \frac{1}{2}\alpha_{\overline{\theta}}\hat{e}_{\overline{\theta}}^{\overline{l}b2} - \gamma\hat{e}_{\overline{\theta}}^{\overline{l}b} \\ \hat{e}_{\overline{\theta}}^{lb} = \underset{e_{\overline{\theta}}}{\operatorname{argmax}}\left\{A_{\underline{\theta}} + \beta_{\underline{\theta}}e_{\overline{\theta}} - \frac{1}{2}\alpha_{\overline{\theta}}e_{\overline{\theta}}{}^2 - \gamma e_{\overline{\theta}}\right\} \\ \hat{e}_{\underline{\theta}}^{lb} = \underset{e_{\underline{\theta}}}{\operatorname{argmax}}\left\{A_{\overline{\theta}} + \beta_{\overline{\theta}}e_{\underline{\theta}} - \frac{1}{2}\alpha_{\underline{\theta}}e_{\underline{\theta}}{}^2 - \gamma e_{\underline{\theta}}\right\} \\ e_{\underline{\theta}}^{lb} \geq e' \end{cases} \tag{A22}$$

As before, in Equation (A22), we assume that constraints (1) and (2) are tight constraints, from which we obtain

$$E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{\rho\left(ue_{\overline{\theta}} - A_{\overline{\theta}} - \beta_{\overline{\theta}}e_{\overline{\theta}}\right) + (1-\rho)\left(ue_{\underline{\theta}} - A_{\underline{\theta}} - \beta_{\underline{\theta}}e_{\underline{\theta}}\right)\right\}$$
$$s.t.\begin{cases} \frac{\beta_{\underline{\theta}}-\gamma}{\alpha_{\underline{\theta}}} = e'(1) \\ A_{\underline{\theta}} + \frac{1}{2}\frac{\left(\beta_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\underline{\theta}}} = 0(2) \\ A_{\overline{\theta}} + \frac{1}{2}\frac{\left(\beta_{\overline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}} = A_{\underline{\theta}} + \frac{1}{2}\frac{\left(\beta_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}}(3) \end{cases} \tag{A23}$$

Substituting the constraints into the objective function in Equation (A23), we obtain

$$E(\pi_b) = \max_{\beta_{\overline{\theta}}}\left\{\begin{array}{l} \rho\left(\left(u - \beta_{\overline{\theta}}\right)\frac{\left(\beta_{\overline{\theta}}-\gamma\right)}{\alpha_{\overline{\theta}}} + \frac{1}{2}\frac{\left(\beta_{\overline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\frac{\left(\alpha_{\underline{\theta}}e'\right)^2}{\alpha_{\underline{\theta}}} - \frac{1}{2}\frac{\left(\alpha_{\underline{\theta}}e'\right)^2}{\alpha_{\overline{\theta}}}\right) \\ +(1-\rho)\left(ue' - \frac{1}{2}\alpha_{\underline{\theta}}e'^2 - \gamma e'\right) \end{array}\right\} \tag{A24}$$

Taking the first partial derivatives of $E(\pi_b)$ with respect to $\beta_{\overline{\theta}}$, according to the first order condition, we obtain

$$\begin{cases} \beta_{\underline{\theta}}^{lb} = \alpha_{\underline{\theta}}e' + \gamma \\ \beta_{\overline{\theta}}^{\overline{l}b} = u \\ A_{\underline{\theta}}^{lb} = -\frac{1}{2}\alpha_{\underline{\theta}}e'^2 \\ A_{\overline{\theta}}^{lb} = -\frac{1}{2}\frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\alpha_{\underline{\theta}}e'^2\left(\frac{\alpha_{\underline{\theta}}}{\alpha_{\overline{\theta}}} - 1\right) \end{cases} \tag{A25}$$

Substituting Equation (A24) into Equation (A22), the level of effort of the agent and the expected benefits for both parties are

$$\begin{cases} e_{\underline{\theta}}^{lh} = e' \\ e_{\overline{\theta}}^{\overline{l}h} = \frac{u-\gamma}{\alpha_{\overline{\theta}}} \end{cases} \tag{A26}$$

$$\begin{cases} E\left(\pi_{s\underline{\theta}}^{lh}\right) = 0 \\ E\left(\pi_{s\overline{\theta}}^{lh}\right) = \frac{1}{2}\left(\alpha_{\underline{\theta}}e'\right)^2\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right) \\ E\left(\pi_b^{lh}\right) = \rho\left(\frac{1}{2}\frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\left(\alpha_{\underline{\theta}}e'\right)^2\left(\frac{1}{\alpha_{\underline{\theta}}} - \frac{1}{\alpha_{\overline{\theta}}}\right)\right) + (1-\rho)\left(ue' - \frac{1}{2}\alpha_{\underline{\theta}}e'^2 - \gamma e'\right) \end{cases} \tag{A27}$$

Appendix D. Model Solution for the Information Asymmetry Scenario When the Principal's Effort Constraint Threshold Satisfies $e^{'} \geq e_{\overline{\theta}}^{sb}$

The original principal–agent model can be rewritten as

$$E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{ \rho\left(ue_{\overline{\theta}}^{lb} - A_{\overline{\theta}} - \beta_{\overline{\theta}}e_{\overline{\theta}}^{lb}\right) + (1-\rho)\left(ue_{\underline{\theta}}^{lb} - A_{\underline{\theta}} - \beta_{\underline{\theta}}e_{\underline{\theta}}^{lb}\right) \right\}$$
$$s.t. \begin{cases} \beta_{\underline{\theta}}^{lb} = \alpha_{\underline{\theta}}e' + \gamma(1) \\ \beta_{\overline{\theta}}^{\overline{l}b} = \alpha_{\overline{\theta}}e' + \gamma(2) \\ A_{\underline{\theta}} + \frac{1}{2}\frac{(\beta_{\underline{\theta}}-\gamma)^2}{\alpha_{\underline{\theta}}} \geq 0(3) \\ A_{\overline{\theta}} + \frac{1}{2}\frac{(\beta_{\overline{\theta}}-\gamma)^2}{\alpha_{\overline{\theta}}} \geq 0(4) \\ A_{\underline{\theta}} + \frac{1}{2}\frac{(\beta_{\underline{\theta}}-\gamma)^2}{\alpha_{\underline{\theta}}} \geq \left(A_{\overline{\theta}} + \frac{1}{2}\frac{(\beta_{\overline{\theta}}-\gamma)^2}{\alpha_{\overline{\theta}}}\right) - \frac{1}{2}(\beta_{\overline{\theta}}-\gamma)^2\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right)(5) \\ A_{\overline{\theta}} + \frac{1}{2}\frac{(\beta_{\overline{\theta}}-\gamma)^2}{\alpha_{\overline{\theta}}} \geq \left(A_{\underline{\theta}} + \frac{1}{2}\frac{(\beta_{\underline{\theta}}-\gamma)^2}{\alpha_{\underline{\theta}}}\right) + \frac{1}{2}(\beta_{\underline{\theta}}-\gamma)^2\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right)(6) \end{cases} \quad \text{(A28)}$$

In Equation (A28), constraints (4) and (5) necessarily holds. We assume that constraints (3) and (6) are tight constraints, and we obtain

$$\begin{cases} \beta_{\underline{\theta}}^{lb} = \alpha_{\underline{\theta}}e' + \gamma(1) \\ \beta_{\overline{\theta}}^{\overline{l}b} = \alpha_{\overline{\theta}}e' + \gamma(2) \\ A_{\underline{\theta}}^{lb} = -\frac{1}{2}\alpha_{\underline{\theta}}e'^2(3) \\ A_{\overline{\theta}}^{lb} = -\frac{1}{2}\alpha_{\overline{\theta}}e'^2 + \frac{1}{2}(\alpha_{\underline{\theta}}e')^2\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right)(4) \end{cases} \quad \text{(A29)}$$

Substituting Equation (A29) into the objective function yields the expected profit of the principal:

$$E(\pi_b) = \rho\left(ue' - \frac{1}{2}\alpha_{\overline{\theta}}e'^2 - \frac{1}{2}(\alpha_{\underline{\theta}}e')^2\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right) - \gamma e'\right) + (1-\rho)\left(ue' - \frac{1}{2}\alpha_{\underline{\theta}}e'^2 - \gamma e'\right) \quad \text{(A30)}$$

The expected profit of the agent is

$$\begin{cases} \pi_{s\underline{\theta}}^{lb} = 0 \\ \pi_{s\overline{\theta}}^{lb} = \frac{1}{2}(\alpha_{\underline{\theta}}e')^2\left(\frac{1}{\alpha_{\overline{\theta}}} - \frac{1}{\alpha_{\underline{\theta}}}\right) \end{cases} \quad \text{(A31)}$$

Appendix E. Solving the Principal–Agent Model after Applying DTs (Considering Agent Time Constraints)

The original problem can be rewritten as

$$E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{ \rho\left((u-\beta_{\overline{\theta}})\frac{\beta_{\overline{\theta}}-\gamma}{\alpha_{\overline{\theta}}} - A_{\overline{\theta}}\right) + (1-\rho)\left(u\frac{\beta_{\underline{\theta}}-\gamma}{\alpha_{\underline{\theta}}} - A_{\underline{\theta}} - \beta_{\underline{\theta}}\frac{\beta_{\underline{\theta}}-\gamma}{\alpha_{\underline{\theta}}}\right) - c_B \right\}$$
$$s.t. \begin{cases} A_{\underline{\theta}} + \frac{1}{2}\frac{(\beta_{\underline{\theta}}-\gamma)^2}{\alpha_{\underline{\theta}}} \geq 0(1) \\ A_{\overline{\theta}} + \frac{1}{2}\frac{(\beta_{\overline{\theta}}-\gamma)^2}{\alpha_{\overline{\theta}}} \geq 0(2) \\ A_{\underline{\theta}} + \frac{1}{2}\frac{(\beta_{\underline{\theta}}-\gamma)^2}{\alpha_{\underline{\theta}}} \geq A_{\overline{\theta}} + \frac{1}{2}\frac{(\beta_{\overline{\theta}}-\gamma)^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}\frac{(\beta_{\overline{\theta}}-\gamma)^2}{\alpha_{\overline{\theta}}}\left(1 - \frac{\alpha_{\theta}}{\alpha_{\overline{\theta}}}\right)(3) \\ A_{\overline{\theta}} + \frac{1}{2}\frac{(\beta_{\overline{\theta}}-\gamma)^2}{\alpha_{\overline{\theta}}} \geq A_{\underline{\theta}} + \frac{1}{2}\frac{(\beta_{\underline{\theta}}-\gamma)^2}{\alpha_{\underline{\theta}}} + \frac{1}{2}\frac{(\beta_{\underline{\theta}}-\gamma)^2}{\alpha_{\underline{\theta}}}\left(1 - \frac{\alpha_{\overline{\theta}}}{\alpha_{\underline{\theta}}}\right)(4) \end{cases} \quad \text{(A32)}$$

As mentioned above, we assume that constraints (1) and (4) in Equation (A32) are tight constraints and substitute them into the objective function to obtain the following:

$$E(\pi_b) = \max_{(\beta_{\underline{\theta}},\beta_{\bar{\theta}})} \left\{ \begin{array}{l} \rho\left(\left(u-\beta_{\bar{\theta}}\right)\frac{\beta_{\bar{\theta}}-\gamma}{\alpha_{\bar{\theta}}} + \frac{1}{2}\frac{\left(\beta_{\bar{\theta}}-\gamma\right)^2}{\alpha_{\bar{\theta}}} - \frac{1}{2}\frac{\left(\beta_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\underline{\theta}}}\left(1-\frac{\alpha_{\bar{\theta}}}{\alpha_{\underline{\theta}}}\right)\right) \\ +(1-\rho)\left(u\frac{\beta_{\underline{\theta}}-\gamma}{\alpha_{\underline{\theta}}} + \frac{1}{2}\frac{\left(\beta_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\underline{\theta}}} - \beta_{\underline{\theta}}\frac{\beta_{\underline{\theta}}-\gamma}{\alpha_{\underline{\theta}}}\right) - c_B \end{array} \right\} \tag{A33}$$

$$\left\{ \begin{array}{l} \frac{\partial E(\pi_b)}{\partial \beta_{\underline{\theta}}} = -\rho\frac{\left(\beta_{\underline{\theta}}-\gamma\right)}{\alpha_{\underline{\theta}}}\left(1-\frac{\alpha_{\bar{\theta}}}{\alpha_{\underline{\theta}}}\right) + (1-\rho)\left(\frac{u}{\alpha_{\underline{\theta}}} - \frac{\beta_{\underline{\theta}}}{\alpha_{\underline{\theta}}}\right) \\ \frac{\partial E(\pi_b)}{\partial \beta_{\bar{\theta}}} = \rho\frac{\left(u-\beta_{\bar{\theta}}\right)}{\alpha_{\bar{\theta}}} \end{array} \right. \tag{A34}$$

$$\left\{ \begin{array}{l} \frac{\partial E(\pi_b)}{\partial {\beta_{\underline{\theta}}}^2} = -\frac{\rho}{\alpha_{\underline{\theta}}}\left(1-\frac{\alpha_{\bar{\theta}}}{\alpha_{\underline{\theta}}}\right) - (1-\rho)\frac{1}{\alpha_{\underline{\theta}}} \\ \frac{\partial E(\pi_b)}{\partial \beta_{\underline{\theta}}\partial \beta_{\bar{\theta}}} = 0 \\ \frac{\partial E(\pi_b)}{\partial \beta_{\bar{\theta}}\partial \beta_{\underline{\theta}}} = 0 \\ \frac{\partial E(\pi_b)}{\partial {\beta_{\bar{\theta}}}^2} = -\frac{\rho}{\alpha_{\bar{\theta}}} \end{array} \right. \tag{A35}$$

The Hessian matrix corresponding to Equation (A35) is

$$H_2 = \begin{bmatrix} \frac{\partial^2 E(\pi_b)}{\partial {\beta_{\underline{\theta}}}^2} & \frac{\partial^2 E(\pi_b)}{\partial \beta_{\underline{\theta}}\partial \beta_{\bar{\theta}}} \\ \frac{\partial^2 E(\pi_b)}{\partial \beta_{\bar{\theta}}\partial \beta_{\underline{\theta}}} & \frac{\partial^2 E(\pi_b)}{\partial {\beta_{\bar{\theta}}}^2} \end{bmatrix} \tag{A36}$$

Obviously, the Hessian matrix H_2 determined by Equation (A36) is negative definite. There is an extreme value of the original objective function. According to the first-order condition, we can obtain

$$\left\{ \begin{array}{l} \beta_{\underline{\theta}}^{bc} = \frac{(1-\rho)\alpha_{\underline{\theta}}}{\alpha_{\underline{\theta}}-\rho\alpha_{\bar{\theta}}}u + \frac{\rho\left(\alpha_{\underline{\theta}}-\alpha_{\bar{\theta}}\right)}{\alpha_{\underline{\theta}}-\rho\alpha_{\bar{\theta}}}\gamma \\ \beta_{\bar{\theta}}^{bc} = u \end{array} \right. \tag{A37}$$

Substituting Equation (A37) into the original objective function and constraints yields the contract parameters given by the principal, the agent's level of effort, and the expected benefits for the principal and agent as Equations (A38)–(A40), respectively.

$$\left\{ \begin{array}{l} A_{\underline{\theta}}^{bc} = -\frac{1}{2\alpha_{\underline{\theta}}}\left(\frac{(1-\rho)\alpha_{\underline{\theta}}}{\alpha_{\underline{\theta}}-\rho\alpha_{\bar{\theta}}}(u-\gamma)\right)^2 \\ A_{\bar{\theta}}^{bc} = -\frac{1}{2}\frac{(u-\gamma)^2}{\alpha_{\bar{\theta}}} + \frac{1}{2}\frac{\left(\beta_{\underline{\theta}}^{bc}-\gamma\right)^2}{\alpha_{\underline{\theta}}}\left(1-\frac{\alpha_{\bar{\theta}}}{\alpha_{\underline{\theta}}}\right) \end{array} \right. \tag{A38}$$

$$\left\{ \begin{array}{l} e_{\underline{\theta}}^{bc} = \frac{(1-\rho)\alpha_{\underline{\theta}}}{\alpha_{\underline{\theta}}-\rho\alpha_{\bar{\theta}}}\left(\frac{u-\gamma}{\alpha_{\underline{\theta}}}\right) \\ e_{\bar{\theta}}^{bc} = \frac{u-\gamma}{\alpha_{\bar{\theta}}} \end{array} \right. \tag{A39}$$

$$\left\{ \begin{array}{l} E\left(\pi_{s\underline{\theta}}^{bc}\right) = 0 \\ E\left(\pi_{s\bar{\theta}}^{bc}\right) = \frac{1}{2}\frac{\left(\beta_{\underline{\theta}}^{bc}-\gamma\right)^2}{\alpha_{\underline{\theta}}}\left(1-\frac{\alpha_{\bar{\theta}}}{\alpha_{\underline{\theta}}}\right) \\ E\left(\pi_b^{bc}\right) = \frac{1}{2}\rho\left(\frac{(u-\gamma)^2}{\alpha_{\bar{\theta}}} - \frac{\left(\beta_{\underline{\theta}}^{bc}-\gamma\right)^2}{\alpha_{\underline{\theta}}}\left(1-\frac{\alpha_{\bar{\theta}}}{\alpha_{\underline{\theta}}}\right)\right) \\ +(1-\rho)\left(\left(u-\beta_{\underline{\theta}}^{bc}\right)\frac{\beta_{\underline{\theta}}^{bc}-\gamma}{\alpha_{\underline{\theta}}} + \frac{1}{2}\frac{\left(\beta_{\underline{\theta}}^{bc}-\gamma\right)^2}{\alpha_{\underline{\theta}}}\right) - c_B \end{array} \right. \tag{A40}$$

Appendix F. Model Solution When the Principal Effort Constraint Satisfies $e_{\underline{\theta}}^{bc} \leq e' \leq e_{\overline{\theta}}^{bc}$ after Applying DTs

Equation (41) can be rewritten as

$$E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{ \rho\left(\left(u-\beta_{\overline{\theta}}\right)\frac{(\beta_{\overline{\theta}}-\gamma)}{\alpha_{\overline{\theta}}} - A_{\overline{\theta}} \right) + (1-\rho)\left(\left(u-\beta_{\underline{\theta}}\right)\frac{(\beta_{\underline{\theta}}-\gamma)}{\alpha_{\underline{\theta}}} - A_{\underline{\theta}} \right) - c_B \right\}$$
$$s.t.\begin{cases} A_{\underline{\theta}} + \frac{1}{2}\frac{\left(\beta_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\underline{\theta}}} \geq A_{\overline{\theta}} + \frac{\left(\beta_{\overline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}}\left(1-\frac{1}{2}\frac{\alpha_{\underline{\theta}}}{\alpha_{\overline{\theta}}}\right)(1) \\ A_{\overline{\theta}} + \frac{1}{2}\frac{\left(\beta_{\overline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}} \geq A_{\underline{\theta}} + \frac{\left(\beta_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\underline{\theta}}}\left(1-\frac{1}{2}\frac{\alpha_{\overline{\theta}}}{\alpha_{\underline{\theta}}}\right)(2) \\ A_{\underline{\theta}} + \frac{1}{2}\frac{\left(\beta_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\underline{\theta}}} \geq 0(3) \\ A_{\overline{\theta}} + \frac{1}{2}\frac{\left(\beta_{\overline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}} \geq 0(4) \\ \beta_{\underline{\theta}} - \gamma \geq \alpha_{\underline{\theta}}e'(5) \\ \beta_{\overline{\theta}} - \gamma \geq \alpha_{\overline{\theta}}e'(6) \end{cases} \tag{A41}$$

According to the previous analysis, it is clear that constraints (4) and (6) necessarily hold in the constraint condition of Equation (A41). We assume that constraints (2), (3) and (5) are tight constraints and substitute it into the objective function to obtain

$$E(\pi_b) = \max_{\beta_{\overline{\theta}}}\left\{ \begin{array}{l} \rho\left(\left(u-\beta_{\overline{\theta}}\right)\frac{(\beta_{\overline{\theta}}-\gamma)}{\alpha_{\overline{\theta}}} + \frac{1}{2}\frac{\left(\beta_{\overline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}} - \frac{1}{2}\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)e'^2 \right) \\ +(1-\rho)\left((u-\gamma)e' - \frac{1}{2}\alpha_{\underline{\theta}}e'^2 \right) - c_B \end{array} \right\} \tag{A42}$$

According to the first order condition, we can obtain the following:

$$\beta_{\overline{\theta}}^{bc} = u \tag{A43}$$

Substituting Equation (A43) into the original function, we obtain

$$\begin{cases} A_{\underline{\theta}}^{bc} = -\frac{1}{2}\alpha_{\underline{\theta}}e'^2 \\ A_{\overline{\theta}}^{bc} = -\frac{1}{2}\frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}} + \frac{1}{2}e'^2\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right) \\ \beta_{\underline{\theta}}^{bc} = \alpha_{\underline{\theta}}e' + \gamma \\ \beta_{\overline{\theta}}^{bc} = u \end{cases} \tag{A44}$$

$$\begin{cases} e_{\underline{\theta}}^{bc} = e' \\ e_{\overline{\theta}}^{bc} = \frac{u-\gamma}{\alpha_{\overline{\theta}}} \\ E\left(\pi_{\underline{\theta}}^{bc}\right) = A_{\underline{\theta}}^{bc} + \frac{1}{2}\frac{\left(\beta_{\underline{\theta}}^{bc}-\gamma\right)^2}{\alpha_{\underline{\theta}}} = 0 \\ E\left(\pi_{\overline{\theta}}^{bc}\right) = A_{\overline{\theta}} + \frac{1}{2}\frac{\left(\beta_{\overline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}} = \frac{1}{2}\left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)e'^2 \\ E\left(\pi_b^{bc}\right) = \frac{1}{2}\rho\left(\frac{(u-\gamma)^2}{\alpha_{\overline{\theta}}} - \left(\alpha_{\underline{\theta}}-\alpha_{\overline{\theta}}\right)e'^2 \right) + (1-\rho)\left((u-\gamma)e' - \frac{1}{2}\alpha_{\underline{\theta}}e'^2 \right) - c_B \end{cases} \tag{A45}$$

Appendix G. Model Analysis When the Effort Constraint Is Satisfied by $e' \geq \frac{u}{\alpha_{\overline{\theta}}}$ after Applying DTs

According to the previous analysis, Equation (44) can be further rewritten as

$$E(\pi_b) = \max_{(A_{\overline{\theta}},\beta_{\overline{\theta}}),(A_{\underline{\theta}},\beta_{\underline{\theta}})} \left\{ \rho\left((u-\beta_{\overline{\theta}}) \frac{\beta_{\underline{\theta}}-\gamma}{\alpha_{\underline{\theta}}} - A_{\overline{\theta}} \right) + (1-\rho)\left((u-\beta_{\underline{\theta}}) \frac{\beta_{\overline{\theta}}-\gamma}{\alpha_{\overline{\theta}}} - A_{\underline{\theta}} \right) - c_B \right\}$$

$$s.t. \begin{cases} A_{\underline{\theta}} + \frac{1}{2}\frac{\left(\beta_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\underline{\theta}}} \geq A_{\overline{\theta}} + \frac{\left(\beta_{\overline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}}\left(1 - \frac{1}{2}\frac{\alpha_{\underline{\theta}}}{\alpha_{\overline{\theta}}}\right)(1) \\ A_{\overline{\theta}} + \frac{1}{2}\frac{\left(\beta_{\overline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}} \geq A_{\underline{\theta}} + \frac{\left(\beta_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\underline{\theta}}}\left(1 - \frac{1}{2}\frac{\alpha_{\overline{\theta}}}{\alpha_{\underline{\theta}}}\right)(2) \\ A_{\underline{\theta}} + \frac{1}{2}\frac{\left(\beta_{\underline{\theta}}-\gamma\right)^2}{\alpha_{\underline{\theta}}} \geq 0(3) \\ A_{\overline{\theta}} + \frac{1}{2}\frac{\left(\beta_{\overline{\theta}}-\gamma\right)^2}{\alpha_{\overline{\theta}}} \geq 0(4) \\ e^{bc}_{\underline{\theta}} = \frac{\beta_{\underline{\theta}}-\gamma}{\alpha_{\underline{\theta}}} \geq e'(5) \\ e^{bc}_{\overline{\theta}} = \frac{\beta_{\overline{\theta}}-\gamma}{\alpha_{\overline{\theta}}} \geq e'(6) \end{cases} \tag{A46}$$

As mentioned above, we assume that constraints (2), (3), (5) and (6) in Equation (A46) are tight constraints and substitute them into the objective function to obtain:

$$\begin{cases} A^{bc}_{\overline{\theta}} = \frac{1}{2}\alpha_{\underline{\theta}}\left(1 - \frac{\alpha_{\overline{\theta}}}{\alpha_{\underline{\theta}}}\right)e'^2 - \frac{1}{2}\alpha_{\overline{\theta}}e'^2 \\ A^{bc}_{\underline{\theta}} = -\frac{1}{2}\alpha_{\underline{\theta}}e'^2 \\ \beta^{bc}_{\underline{\theta}} = \alpha_{\underline{\theta}}e' + \gamma \\ \beta^{bc}_{\overline{\theta}} = \alpha_{\overline{\theta}}e' + \gamma \end{cases} \tag{A47}$$

$$\begin{cases} E\left(\pi^{bc}_{\underline{\theta}}\right) = 0 \\ E\left(\pi^{bc}_{\overline{\theta}}\right) = \frac{1}{2}\alpha_{\underline{\theta}}e'^2\left(1 - \frac{\alpha_{\overline{\theta}}}{\alpha_{\underline{\theta}}}\right) \\ E(\pi^{bc}_b) = (u-\gamma)e' - \frac{1}{2}\alpha_{\underline{\theta}}e'^2 - c_B \end{cases} \tag{A48}$$

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