Air Traffic Delays, Safety, and Regulator's Objectives: A Monopoly Case*

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Abstract

Aimed at reducing air traffic delays, this paper proposes a contract signed between the regulator and the monopoly airline to implement a delay reduction service. Different from previous literature, in this paper, the expected delays per flight are only a function of safety levels and the regulator's objective function is a weighted sum of the monopoly airline's profit, passenger surplus, and the regulator's profit. This paper first derives and compares the optimal contracts under complete and incomplete information. Then, this paper shows that the effects of the increases of safety levels on the optimal degrees of the delay reduction service depend on the safety elasticity of delay and the safety elasticity of cost. This paper also shows that the changes of the weights can create different incentives for the regulator to adjust the optimal degrees. Moreover, this paper proposes some relevant policy suggestions for the regulator.

Keywords: Air traffic delays, Safety, Regulator's objectives, Contract, Policy suggestions.

JEL classification: D82, D86, L93, R41.

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1 Introduction

The Single European Sky program started by European Commission at 2004 aims at satisfying future capacity and safety needs at a European level. European Commission plans to enable a 3-fold increase in capacity which also reduces air traffic delays, improve the safety performance by a factor of 10, and enable a 10% reduction in the effects flights have on the environment.[1] Particularly, in the Single European Sky ATM[2] Research (SESAR) program, airlines can reveal their preferences in the regulation, which means that the regulator can sell services to airlines to help them reduce delays and costs. The motivation of this paper is to study the optimal contracts signed between the regulator and the monopoly airline and to propose some relevant policy suggestions for the regulator.

In general, congestion and safety consideration are the two main factors resulting in air traffic delays. According to Cohen et al. (2009), if airlines neglect the costs they impose on the others, they always schedule more flights exceeding the capacity of airspace and airports. Then, congestion may probably happen. This is the congestion externality problem. Generally speaking, there is a trade-off between safety levels and delays, i.e., the higher the safety level the regulator maintains is, the more likely the delays happen. Some accidental factors, for example, bad weather and technical problems, are serious threats to air traffic safety. Thus, the regulator may create some delays to ensure safety.

To solve the congestion externality problem, there are mainly two kinds of approaches, price-based approaches (Basso (2008), Brueckner (2002), Pels and Verhoef (2004), Yang and Zhang (2011), and Zhang and Zhang (2003, 2006, 2010)) and quantity-based approaches (Basso and Zhang (2010), Brueckner (2009), Cohen et al. (2009), Czerny (2010), and Verhoef (2010)). According to Brueckner (2009), under price-based approaches, the airport declares a charge per flight and then airlines choose the number of flights they wish to schedule. Price-based approaches can be implemented by either a differenti-

[1] European Air Traffic Management Master Plan (2009).
[2] ATM is an abbreviation for Air Traffic Management.

ated, airline-specific congestion toll, or a uniform per-flight charge. Particularly, Brueckner (2002) studied the optimal congestion toll under different market structures. If the airport is used by a monopoly airline, congestion can be fully internalized and thus there is no need to charge congestion toll. However, if the airport is used by several airlines, congestion can just be partially internalized and thus a toll is needed for uninternalized congestion. According to Brueckner (2009), under quantity-based approaches, the airport declares a total desired number of flights and then achieves by allocating a corresponding number of slots. Quantity-based approaches can be implemented by either a slot-distribution regime where a fixed total number of slots are distributed for free and then airlines are permitted to trade as they want, or a slot-auction regime where slots are completely allocated through an auction.

This paper, however, will not focus on congestion. On the one hand, according to the goals of Single European Sky program, capacity will greatly expand, which implies that congestion may no longer be a serious problem in the future European sky and airports. On the other hand, this paper studies a monopoly case. According to Brueckner (2002), congestion can be fully internalized by a monopoly airline and thus does not exist. Therefore, this paper will use a new delay function, which is proposed in Wang (2013). Specifically, instead of the total number of flights and airport capacities, we will only model safety levels into the delay function, which is also consistent with the observation that safety consideration is the other main source of delays except congestion. To reduce the delays caused mainly by safety consideration, we will introduce a delay reduction service which can be provided by the regulator. In the SESAR program, a new generation air traffic management system will be used by the regulator in the future, which makes a better coordination for flights possible. Thus, technically, the regulator will have the ability to reduce delays through the new management system. From the economic aspect, the regulator can sell the delay reduction service through a contract, in which the degree of the delay reduction service the regulator provides to the airline and the transfer the airline pays to the regulator are formulated.

This paper is in fact a further study of Wang (2013), where the regulator sells the delay reduction service to duopoly airlines through a second-price sealed-bid auction. Wang (2013) focused on the relationship between the airlines' equilibrium bids and their types, the effect of the increases of safety levels on the regulator's equilibrium revenue, and in equilibrium, the effects of the mechanism on airlines competition and passenger surplus. This paper, however, derives and compares the optimal contracts under complete and incomplete information and studies the effects of the increases of safety levels on the optimal degrees of the delay reduction service. In this paper, the regulator's objective function is a weighted sum of the monopoly airline's profit, passenger surplus, and the regulator's profit. Therefore, this paper also studies the effects of the changes of the weights on the optimal degrees of the delay reduction service.

In particular, there is a significant difference between this paper and some regulation literature (Baron and Besanko (1984), Baron and Myerson (1982), and Laffont and Tirole (1986)). In those studies, the regulator's objective function is a weighted sum of consumer and producer surplus. In this paper, however, as we have described, the regulator's objective function also includes its own profit.

To briefly summarize, this paper contributes to the literature of air traffic delays on three aspects. First, this paper uses a new delay function and a new regulator's objective function. Second, this paper proposes a contract to implement a delay reduction service. Specifically, the optimal contracts are incentive feasible and passengers can enjoy benefits from them. Third, this paper proposes some relevant policy suggestions for the regulator.

The remainder of the paper is organized as follows. Section 2 introduces the model. Section 3 derives and compares the optimal contracts under complete and incomplete information. Moreover, this section studies the effects of the increases of safety levels and the changes of the weights on the optimal degrees of the delay reduction service. Besides, this section also studies four examples to illustrate some results. Section 4 concludes the paper and summarizes the policy suggestions proposed in the paper.

2 The Model

In this paper, the regulator sells a delay reduction service to the monopoly airline through a contract.

Suppose that the monopoly airline is risk neutral and its profit before signing this contract is

$$\pi = A - \theta D(S),$$

where A is a parameter with $A > 0$, θ denotes the airline's value of time, S denotes the safety levels the regulator maintains, and $D(S)$ denotes the expected delays per flight.

From this equation, we can see that the monopoly airline's profit decreases with air traffic delays.

We define θ as the airline's type. θ may be unobservable to the regulator. However, it is common knowledge that θ belongs to the set $\Theta = \left\{\overline{\theta}, \underline{\theta}\right\}$ where $\overline{\theta}, \underline{\theta} > 0$ and $\triangle\theta = \overline{\theta} - \underline{\theta} > 0$. If θ is the airline's private knowledge, we assume that the airline can be either the one with type $\overline{\theta}$ or $\underline{\theta}$ with probabilities v and $1 - v$ respectively. For the safety levels, we assume that a safety level is set by the regulator ex ante and satisfies the minimum requirement. Moreover, we assume that the expected delays per flight $D(S)$ strictly increase with safety levels S, i.e., $D'(S) > 0$, which captures the fact that the higher safety level the regulator maintains is, the more likely the delays happen.

Remark 1. Usually, the delay function is modeled as $\frac{Q}{K(K-Q)}$. The US Federal Aviation Administration (1969) first proposed this specification and Horonjeff and McKelvey (1983) made a further discussion. Many studies, for example, Basso (2008), Morrison (1987), Oum et al. (2004), and Zhang and Zhang (1997), used this specification in their models. Moreover, Yang and Zhang (2011) used a delay function which was linear in Q. In this paper, however, just because of the reasons we have discussed in Section 1, we use a new delay function, which is proposed in Wang (2013). Specifically, the expected delays per flight are only a function of safety levels, i.e., $D(S)$.

The regulator signs a contract with the monopoly airline. The contracting variables are R and T, where R is the degree of the delay reduction service the regulator provides to the airline and T is the transfer the airline pays to the regulator. After obtaining the delay reduction service, the monopoly airline's profit becomes

$$\pi = A - \theta D(S)[1 - \alpha(R)] - T,$$

where $\alpha(R)$ is the fraction of delay reduction the airline can enjoy if the degree of the delay reduction service it purchases is R.

We assume $\alpha'(R) > 0$, $\alpha''(R) < 0$, and $\alpha(0) = 0$. This assumption implies that the marginal value of the delay reduction service is positive but strictly decreasing with the degree and the airline cannot enjoy any benefit if the degree it purchases is zero.

Remark 2. In general, an airline has private knowledge mainly on two aspects, the fraction of delay reduction and the value of time. Wang (2013) models according to the first aspect while this paper models according to the second one.

Suppose that passenger surplus is

$$PS = B - \beta D(S),$$

where B is a parameter with $B > 0$ and β denotes the passengers' value of time.

From this equation, we can see that passenger surplus decreases with air traffic delays.

After the airline signs the contract, passengers will also enjoy delay reduction but pay nothing. Thus, passenger surplus becomes

$$PS = B - \beta D(S)[1 - \alpha(R)].$$

We assume that the regulator tries to use the transfer to cover the cost of providing the delay reduction service. If the transfer is not enough, the regulator will use the revenue from its other activities. Then, according to this assumption, we can write the regulator's profit, i.e.,

$$\phi = T - C(S)R,$$

where $C(S)$ is the regulator's marginal cost of providing the delay reduction service, given a safety level.

We assume that the regulator's marginal cost $C(S)$ strictly increases with safety levels S, i.e., $C'(S) > 0$. In fact, when providing the delay reduction service, the regulator has to schedule more staff if it hopes to achieve a higher safety level, which will inevitable result in a higher cost.

Because the regulator tries to use the transfer to cover the cost, it may have incentive to include its own profit as a part of its objective function.

Suppose that the regulator's objective function is a weighted sum of the monopoly airline's profit, passenger surplus, and the regulator's profit, i.e.,

$$W = \lambda_1 \pi + \lambda_2 PS + \lambda_3 \phi,$$

where λ_1, λ_2, and λ_3 are the weights of π, PS, and ϕ respectively with $\lambda_1, \lambda_2, \lambda_3 \geqslant 0$ and $\lambda_1 + \lambda_2 + \lambda_3 = 1$.

Remark 3. The regulator's objective function in this paper is significantly different from the one in some regulation literature. In those studies, the regulator's objective function is a weighted sum of consumer and producer surplus, without the regulator's profit.

Moreover, we assume that the regulator values more its own profit than the monopoly airline's profit, i.e., $\lambda_3 \geqslant \lambda_1$. In fact, when $\lambda_3 < \lambda_1$, the regulator will optimally set the transfer as lower as possible, which contradicts to the assumption that the regulator tries to use the transfer to cover the cost.

Remark 4. From the equations above, we can clearly see that the model does not involve the airline's decision about the optimal number of flights it will schedule. The reason to make this assumption is to simplify the airline's decision process and thus facilitate us to focus on the regulator's decisions.

The timeline is shown in Firgure 1.

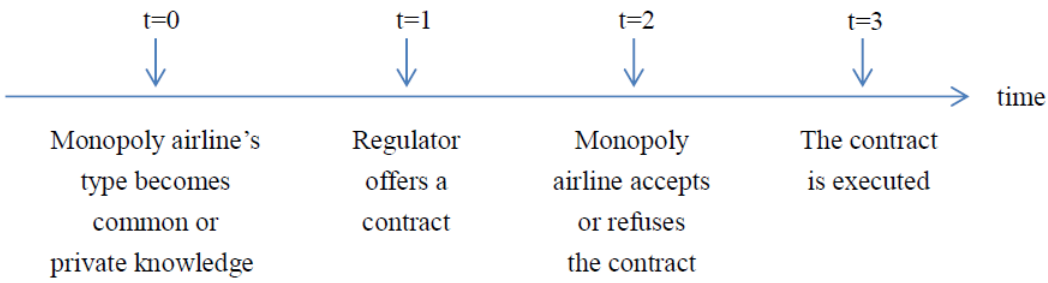

Figure 1: Timeline

3 Analysis of the Optimal Contracts

3.1 Optimal Contracts

We first assume that the optimal contracts can ensure $(\beta+\theta) D(S) \alpha(R) - C(S) R \geqslant 0$. Only under this assumption, the delay reduction service is socially valuable.

Under complete information, the monopoly airline's type is common knowledge. The regulator's optimization program for the airline with type $\overline{\theta}$ can be written as

$$\begin{aligned} \max_{\{(\overline{R},\overline{T})\}} \overline{W} &= \lambda_1 \left\{A - \overline{\theta} D(S) \left[1-\alpha\left(\overline{R}\right)\right] - \overline{T}\right\} + \lambda_2 \left\{B - \beta D(S) \left[1-\alpha\left(\overline{R}\right)\right]\right\} \\ &\quad + \lambda_3 \left[\overline{T} - C(S) \overline{R}\right] \end{aligned}$$

$$\text{subject to } A - \overline{\theta} D(S) \left[1-\alpha\left(\overline{R}\right)\right] - \overline{T} \geqslant A - \theta D(S).$$

In this optimization program, $\overline{R}$ and $\overline{T}$ denote the degree of the delay reduction service and the transfer respectively the regulator designs for the airline with type $\overline{\theta}$. Besides, the constraint is the monopoly airline's participation constraint.

Define $\overline{U} = \overline{\theta} D(S) \alpha\left(\overline{R}\right) - \overline{T}$. Plugging $\overline{T} = \overline{\theta} D(S) \alpha\left(\overline{R}\right) - \overline{U}$ into the optimization program, we can obtain

$$\begin{aligned}\max_{\{(\overline{R},\overline{U})\}} \overline{W} &= \lambda_1 \left[A - \overline{\theta} D(S)\right] + \lambda_2 \left\{B - \beta D(S)\left[1 - \alpha\left(\overline{R}\right)\right]\right\} \\ &\quad + \lambda_3 \left[\overline{\theta} D(S) \alpha\left(\overline{R}\right) - C(S)\overline{R}\right] - (\lambda_3 - \lambda_1)\overline{U}\end{aligned}$$

$$\text{subject to } \overline{U} \geqslant 0.$$

Optimally, the regulator will set $\overline{U} = 0$. Plugging it into the objective function and taking the first order condition with respect to $\overline{R}$, we can obtain

$$\alpha'\left(\overline{R}^{FB}\right) = \frac{\lambda_3 C(S)}{\left(\lambda_2 \beta + \lambda_3 \overline{\theta}\right) D(S)}, \tag{1}$$

where $\overline{R}^{FB}$ is the first-best degree of the delay reduction service for the airline with type $\overline{\theta}$ from the regulator's perspective.

For the second order derivative, we have $\left(\lambda_2 \beta + \lambda_3 \overline{\theta}\right) D(S) \alpha''\left(\overline{R}^{FB}\right) < 0$, which implies that $\overline{R}^{FB}$ maximizes the objective function.

Then, the first-best transfer for the airline with type $\overline{\theta}$ is

$$\overline{T}^{FB} = \overline{\theta} D(S) \alpha\left(\overline{R}^{FB}\right). \tag{2}$$

In exactly the same way, we can obtain the first-best degree of the delay reduction service and the first-best transfer for the airline with type $\underline{\theta}$, i.e.,

$$\alpha'\left(\underline{R}^{FB}\right) = \frac{\lambda_3 C(S)}{\left(\lambda_2 \beta + \lambda_3 \underline{\theta}\right) D(S)}, \tag{3}$$

$$\underline{T}^{FB} = \underline{\theta} D(S) \alpha\left(\underline{R}^{FB}\right). \tag{4}$$

Finally, Lemma 1 summarizes the optimal contracts under complete information.

Lemma 1. *Under complete information, the optimal contracts are* $\left(\overline{R}^{FB}, \overline{T}^{FB}\right)$ *if* $\theta = \overline{\theta}$ *and* $\left(\underline{R}^{FB}, \underline{T}^{FB}\right)$ *if* $\theta = \underline{\theta}$, *where* $\overline{R}^{FB}$, $\overline{T}^{FB}$, $\underline{R}^{FB}$, *and* $\underline{T}^{FB}$ *are given by (1) to (4).*

According to (1) and (3), because of $\overline{\theta} > \underline{\theta}$ and $\alpha'' (R) < 0$, we can obtain $\overline{R}^{FB} \geqslant \underline{R}^{FB}$. This implies that, under complete information, the airline with a higher value of time will enjoy a higher degree of the delay reduction service.

Then, we will derive the optimal menu of contracts under incomplete information.

According to Laffont and Martimort (2002), we first give the definition of *incentive compatible.*

Definition 1. *A menu of contracts $\left\{ \left(\overline{R}, \overline{T}\right); \left(\underline{R}, \underline{T}\right) \right\}$ is incentive compatible when $\left(\overline{R}, \overline{T}\right)$ is weakly preferred to $\left(\underline{R}, \underline{T}\right)$ by the airline with type $\overline{\theta}$ and $\left(\underline{R}, \underline{T}\right)$ is weakly preferred to $\left(\overline{R}, \overline{T}\right)$ by the airline with type $\underline{\theta}$.*

Under incomplete information, the monopoly airline's type is its private knowledge. In this case, in order to have the airline self-selecting properly within the menu, the incentive compatibility constraints for the airline with type $\overline{\theta}$ and $\underline{\theta}$ must be satisfied, i.e.,

$$A - \overline{\theta} D(S) \left[1 - \alpha\left(\overline{R}\right)\right] - \overline{T} \geqslant A - \overline{\theta} D(S) \left[1 - \alpha\left(\underline{R}\right)\right] - \underline{T}, \tag{5}$$

$$A - \underline{\theta} D(S) \left[1 - \alpha\left(\underline{R}\right)\right] - \underline{T} \geqslant A - \underline{\theta} D(S) \left[1 - \alpha\left(\overline{R}\right)\right] - \overline{T}. \tag{6}$$

Moreover, the participation constraints must also be satisfied, i.e.,

$$A - \overline{\theta} D(S) \left[1 - \alpha\left(\overline{R}\right)\right] - \overline{T} \geqslant A - \overline{\theta} D(S), \tag{7}$$

$$A - \underline{\theta} D(S) \left[1 - \alpha\left(\underline{R}\right)\right] - \underline{T} \geqslant A - \underline{\theta} D(S). \tag{8}$$

Then, according to Laffont and Martimort (2002), we give the definition of *incentive feasible.*

Definition 2. *A menu of contracts is incentive feasible if it satisfies both the incentive compatibility and the participation constraints (5) through (8).*

Under incomplete information, the regulator's optimization program can be written as

$$\begin{aligned}\max_{\left\{\left(\overline{R},\overline{T}\right);\left(\underline{R},\underline{T}\right)\right\}} W &= v\left\{\lambda_1\left\{A-\overline{\theta}D\left(S\right)\left[1-\alpha\left(\overline{R}\right)\right]-\overline{T}\right\}+\lambda_2\left\{B-\beta D\left(S\right)\left[1-\alpha\left(\overline{R}\right)\right]\right\}\right.\\ &\quad\left.+\lambda_3\left[\overline{T}-C\left(S\right)\overline{R}\right]\right\}+\left(1-v\right)\left\{\lambda_1\left\{A-\underline{\theta}D\left(S\right)\left[1-\alpha\left(\underline{R}\right)\right]-\underline{T}\right\}\right.\\ &\quad\left.+\lambda_2\left\{B-\beta D\left(S\right)\left[1-\alpha\left(\underline{R}\right)\right]\right\}+\lambda_3\left[\underline{T}-C\left(S\right)\underline{R}\right]\right\}\end{aligned}$$

subject to (5) to (8).

Define $\overline{U}=\overline{\theta}D\left(S\right)\alpha\left(\overline{R}\right)-\overline{T}$ and $\underline{U}=\underline{\theta}D\left(S\right)\alpha\left(\underline{R}\right)-\underline{T}$ as the information rent of the airline with type $\overline{\theta}$ and $\underline{\theta}$ respectively. Plugging $\overline{T}=\overline{\theta}D\left(S\right)\alpha\left(\overline{R}\right)-\overline{U}$ and $\underline{T}=\underline{\theta}D\left(S\right)\alpha\left(\underline{R}\right)-\underline{U}$ into the optimization program, we can obtain

$$\begin{aligned}\max_{\left\{\left(\overline{R},\overline{U}\right);\left(\underline{R},\underline{U}\right)\right\}} W &= v\left\{\lambda_1\left[A-\overline{\theta}D\left(S\right)\right]+\lambda_2\left\{B-\beta D\left(S\right)\left[1-\alpha\left(\overline{R}\right)\right]\right\}\right.\\ &\quad\left.+\lambda_3\left[\overline{\theta}D\left(S\right)\alpha\left(\overline{R}\right)-C\left(S\right)\overline{R}\right]\right\}+\left(1-v\right)\left\{\lambda_1\left[A-\underline{\theta}D\left(S\right)\right]\right.\\ &\quad\left.+\lambda_2\left\{B-\beta D\left(S\right)\left[1-\alpha\left(\underline{R}\right)\right]\right\}+\lambda_3\left[\underline{\theta}D\left(S\right)\alpha\left(\underline{R}\right)-C\left(S\right)\underline{R}\right]\right\}\\ &\quad-\left(\lambda_3-\lambda_1\right)\left[v\overline{U}+\left(1-v\right)\underline{U}\right]\end{aligned}$$

subject to

$$\overline{U}\geqslant\underline{U}+\triangle\theta D\left(S\right)\alpha\left(\underline{R}\right), \tag{9}$$

$$\overline{U}\geqslant 0, \tag{10}$$

$$\underline{U}\geqslant\overline{U}-\triangle\theta D\left(S\right)\alpha\left(\overline{R}\right), \tag{11}$$

$$\underline{U}\geqslant 0. \tag{12}$$

We can find that (9) and (12) bind, i.e., $\overline{U}=\triangle\theta D\left(S\right)\alpha\left(\underline{R}\right)$ and $\underline{U}=0$. Plugging them into the objective function and taking the first order condition with respect to $\overline{R}$ and $\underline{R}$, we can obtain

$$\alpha'\left(\overline{R}^{SB}\right) = \frac{\lambda_3 C(S)}{\left(\lambda_2\beta + \lambda_3\overline{\theta}\right) D(S)}, \tag{13}$$

$$\alpha'\left(\underline{R}^{SB}\right) = \frac{\lambda_3 C(S)}{\left[\lambda_2\beta + \lambda_3\underline{\theta} - \frac{v}{1-v}\left(\lambda_3 - \lambda_1\right)\triangle\theta\right] D(S)}. \tag{14}$$

where $\overline{R}^{SB}$ and $\underline{R}^{SB}$ are the second-best degrees of the delay reduction service for the airline with type $\overline{\theta}$ and $\underline{\theta}$ respectively from the regulator's perspective.

For the second order derivative, we have $\left[\lambda_2\beta + \lambda_3\overline{\theta}\right] D(S)\,\alpha''\left(\overline{R}^{SB}\right) < 0$. Moreover, by assuming $\lambda_2\beta + \lambda_3\underline{\theta} > \frac{v}{1-v}\left(\lambda_3 - \lambda_1\right)\triangle\theta$,[3] we also have $\left[\lambda_2\beta + \lambda_3\underline{\theta} - \frac{v}{1-v}\left(\lambda_3 - \lambda_1\right)\triangle\theta\right] D(S)\,\alpha''\left(\underline{R}^{SB}\right) < 0$. These conditions imply that $\overline{R}^{SB}$ and $\underline{R}^{SB}$ maximize the objective function.

Besides, we also have to check the other two omitted constraints. Obviously, $\overline{U} \geqslant 0$ can be satisfied. According to (13) and (14), the monotonicity constraint $\overline{R}^{SB} \geqslant \underline{R}^{SB}$ is satisfied. Thus, we can also validate $\underline{U} \geqslant \overline{U} - \triangle\theta D(S)\,\alpha\left(\overline{R}\right)$.

Then, the second-best transfers for the airline with type $\overline{\theta}$ and $\underline{\theta}$ are, respectively,

$$\overline{T}^{SB} = \overline{\theta} D(S)\,\alpha\left(\overline{R}^{SB}\right) - \triangle\theta D(S)\,\alpha\left(\underline{R}^{SB}\right), \tag{15}$$

$$\underline{T}^{SB} = \underline{\theta} D(S)\,\alpha\left(\underline{R}^{SB}\right). \tag{16}$$

Finally, Lemma 2 summarizes the optimal menu of contracts under incomplete information.

Lemma 2. *Under incomplete information, the optimal menu of contracts* $\left\{\left(\overline{R}^{SB}, \overline{T}^{SB}\right); \left(\underline{R}^{SB}, \underline{T}^{SB}\right)\right\}$ *is incentive feasible and given by (13) to (16). Besides, only the airline with type* $\overline{\theta}$ *gets a positive information rent given by* $\overline{U}^{SB} = \triangle\theta D(S)\,\alpha\left(\underline{R}^{SB}\right)$.

We have seen $\overline{R}^{SB} \geqslant \underline{R}^{SB}$. This implies that, under incomplete information, the airline with a higher value of time will enjoy a higher degree of the

[3]This assumption excludes corner solution, i.e., the regulator finds it optimal not to sign a contract with the airline with type $\underline{\theta}$.

delay reduction service.

3.2 Analysis

We first compare the optimal contracts under complete and incomplete information. The comparison for the optimal degrees of the delay reduction service is given in Proposition 1.

Proposition 1. *Under incomplete information, for the optimal degrees of the delay reduction service, there is no distortion for the airline with type $\overline{\theta}$ with respect to the first-best, i.e., $\overline{R}^{SB} = \overline{R}^{FB}$. However, for the airline with type $\underline{\theta}$, with respect to the first-best,*

1. *there is a downward distortion, i.e., $\underline{R}^{SB} < \underline{R}^{FB}$, when $\lambda_3 > \lambda_1$;*
2. *there is no distortion, i.e., $\underline{R}^{SB} = \underline{R}^{FB}$, when $\lambda_3 = \lambda_1$.*

Proof. According to Lemma 1 and 2, we have $\alpha' \left(\overline{R}^{SB}\right) = \alpha' \left(\overline{R}^{FB}\right)$, which implies $\overline{R}^{SB} = \overline{R}^{FB}$, i.e., under incomplete information, for the airline with type $\overline{\theta}$, there is no distortion with respect to the first-best. When $\lambda_3 > \lambda_1$, we have $\alpha' \left(\underline{R}^{SB}\right) > \alpha' \left(\underline{R}^{FB}\right)$, which implies $\underline{R}^{SB} < \underline{R}^{FB}$, i.e., under incomplete information, for the airline with type $\underline{\theta}$, there is a downward distortion with respect to the first-best. When $\lambda_3 = \lambda_1$, we have $\alpha' \left(\underline{R}^{SB}\right) = \alpha' \left(\underline{R}^{FB}\right)$, which implies $\underline{R}^{SB} = \underline{R}^{FB}$, i.e., under incomplete information, for the airline with type $\underline{\theta}$, there is no distortion with respect to the first-best. □

In the relevant literature, due to the asymmetric information, there always exists downward distortion. In this paper, however, there also exists the case where there is no distortion. In the following part, we will see how the regulator makes decisions.

Under incomplete information, the regulator's objective function can be written as

$$\begin{aligned} \max_{\left\{\left(\overline{R},\underline{R}\right)\right\}} W &= \lambda_1 \left\{A - \left[v\overline{\theta} + (1-v)\underline{\theta}\right] D(S)\right\} + \lambda_2 \left[B - \beta D(S)\right] \\ &\quad + EAE - EIR, \end{aligned} \tag{17}$$

where EAE denotes the *Expected Allocative Efficiency*, EIR denotes the *Expected Information Rent*, and

$$\begin{aligned} EAE &= v\left\{\left(\lambda_2\beta+\lambda_3\overline{\theta}\right)D\left(S\right)\alpha\left(\overline{R}\right)-\lambda_3 C\left(S\right)\overline{R}\right\} \\ &\quad +\left(1-v\right)\left\{\left(\lambda_2\beta+\lambda_3\underline{\theta}\right)D\left(S\right)\alpha\left(\underline{R}\right)-\lambda_3 C\left(S\right)\underline{R}\right\}, \end{aligned}$$

$$\begin{aligned} EIR &= v\left(\lambda_3-\lambda_1\right)\overline{U}+\left(1-v\right)\left(\lambda_3-\lambda_1\right)\underline{U} \\ &= \left(\lambda_3-\lambda_1\right)v\triangle\theta D\left(S\right)\alpha\left(\underline{R}\right). \end{aligned}$$

In the regulator's objective function, the expected information rent does not depend on $\overline{R}$, which implies that, under incomplete information, the regulator has no incentive to distort $\overline{R}$. Then, we have $\overline{R}^{SB}=\overline{R}^{FB}$.

However, the expected information rent does depend on $\underline{R}$. Therefore, according to the values of λ_1 and λ_3, we will analyze the regulator's incentive about distorting $\underline{R}$.

When $\lambda_3>\lambda_1$, reducing the expected information rent will increase the value of the objective function. Therefore, under incomplete information, optimally, the regulator will distort downward $\underline{R}$ to reduce the information rent left to the airline with type $\overline{\theta}$ and thus the expected information rent. Then, we have $\underline{R}^{SB}<\underline{R}^{FB}$.

Under $\lambda_3>\lambda_1$, maximizing the objective function (17) with respect to $\underline{R}$, we can obtain

$$\left(1-v\right)\left\{\left(\lambda_2\beta+\lambda_3\underline{\theta}\right)D\left(S\right)\alpha^{'}\left(\underline{R}\right)-\lambda_3 C\left(S\right)\right\}=v\left(\lambda_3-\lambda_1\right)\triangle\theta D\left(S\right)\alpha^{'}\left(\underline{R}\right).$$

From the equation above, for the regulator, we can find a trade-off between efficiency and rent extraction. The left-hand side is the efficiency gains of the regulator from the infinitesimal increase of $\underline{R}$ while the right-hand side is the rent increase of the airline with type $\overline{\theta}$ from the infinitesimal increase of $\underline{R}$. In fact, $\underline{R}^{SB}$ is the value which balances the trade-off.

When $\lambda_3 = \lambda_1$, there is no expected information rent in the regulator's objective function. Therefore, under incomplete information, optimally, the regulator will not distort $\underline{R}$. Then, we have $\underline{R}^{SB} = \underline{R}^{FB}$.

Under $\lambda_3 = \lambda_1$, unlike the relevant literature, for the regulator, the trade-off between efficiency and rent extraction does not exist, which is due to the fact that the monopoly airline's profit is included in the regulator's objective function.

In fact, for the case where $\lambda_3 = \lambda_1$, the amounts of the information rents do not affect the value of the objective function. Therefore, if we only consider the value of the objective function, optimally, the information rents can be $\overline{U} = \triangle\theta D(S)\,\alpha\left(\underline{R}^{SB}\right) + \gamma + \delta$ and $\underline{U} = \gamma$, where $\gamma, \delta \geqslant 0$, which implies that the transfers for the airline with type $\overline{\theta}$ and $\underline{\theta}$ will be lower than $\overline{T}^{SB}$ and $\underline{T}^{SB}$ respectively. However, we have assumed that the regulator tries to use the transfer to cover the cost. Under this assumption, the regulator will only leave the necessary information rents for the airline, i.e., $\gamma = \delta = 0$. Therefore, under incomplete information, when $\lambda_3 = \lambda_1$, the optimal transfers will still be $\overline{T}^{SB} = \overline{\theta}D(S)\,\alpha\left(\overline{R}^{SB}\right) - \triangle\theta D(S)\,\alpha\left(\underline{R}^{SB}\right)$ and $\underline{T}^{SB} = \underline{\theta}D(S)\,\alpha\left(\underline{R}^{SB}\right)$.

Then, the comparison for the optimal transfers is given in Corollary 1.

Corollary 1. *For the airline with type $\overline{\theta}$, $\overline{T}^{SB} < \overline{T}^{FB}$. For the airline with type $\underline{\theta}$, $\underline{T}^{SB} < \underline{T}^{FB}$, when $\lambda_3 > \lambda_1$; $\underline{T}^{SB} = \underline{T}^{FB}$, when $\lambda_3 = \lambda_1$.*

Proof. According to Lemma 1 and 2, we can easily see Corollary 1. Thus, the proof is omitted henceforth. □

In Corollary 1, for the airline with type $\overline{\theta}$, the reason why the second-best transfer is lower than the first-best one is that, under incomplete information, the airline with type $\overline{\theta}$ can obtain the information rent. For the airline with type $\underline{\theta}$, the comparison depends on whether the regulator distorts downward $\underline{R}$ under incomplete information. When $\lambda_3 > \lambda_1$, the regulator distorts downward $\underline{R}$, which implies that the second-best transfer is lower than the first-best one. When $\lambda_3 = \lambda_1$, the regulator does not distort $\underline{R}$, which implies that the second-best transfer is equal to the first-best one.

From Proposition 1 and Corollary 1, we can see that, under incomplete information, the regulator can achieve the first-best contract except a lower transfer for the airline with type $\overline{\theta}$, as long as it values equally its own profit and the monopoly airline's profit.

Undoubtedly, safety is one of the most important factors in the air transport industry and the regulator always has incentives to increase safety levels. Therefore, we should study the effects of the increases of safety levels on the optimal degrees of the delay reduction service, which may provide some suggestions for the regulator about setting safety levels. Before proceeding to Proposition 2, we first give two definitions, the *safety elasticity of delay* and the *safety elasticity of cost*.

Definition 3. *The safety elasticity of delay is defined as*

$$\epsilon_{D,S} = \frac{dD\left(S\right)}{D\left(S\right)}\frac{S}{dS}.$$

According to this definition, we can see that the safety elasticity of delay $\epsilon_{D,S}$ measures the percentage change in delay in response to a one percent change in safety level.

Definition 4. *The safety elasticity of cost is defined as*

$$\epsilon_{C,S} = \frac{dC\left(S\right)}{C\left(S\right)}\frac{S}{dS}.$$

In a similar way, the safety elasticity of cost $\epsilon_{C,S}$ measures the percentage change in cost in response to a one percent change in safety level.

Then, Proposition 2 summarizes the effects of the increases of safety levels on the optimal degrees of the delay reduction service.

Proposition 2. *The optimal degrees of the delay reduction service* $\overline{R}^{FB}$*,* $\underline{R}^{FB}$*,* $\overline{R}^{SB}$*, and* $\underline{R}^{SB}$ *increase (resp. decrease) with safety levels* S *when* $\epsilon_{D,S} \geqslant$ *(resp.* $<$*)* $\epsilon_{C,S}$*.*

Proof. Taking the derivative of $\alpha'\left(\overline{R}^{FB}\right)$ in Lemma 1 with respect to S, we can obtain

$$\frac{\partial \alpha'\left(\overline{R}^{FB}\right)}{\partial S}=\frac{\lambda_3\left[C'\left(S\right)D\left(S\right)-C\left(S\right)D'\left(S\right)\right]}{\left(\lambda_2\beta+\lambda_3\overline{\theta}\right)D^2\left(S\right)}.$$

Therefore, $\overline{R}^{FB}$ increases with safety levels S when

$$C'\left(S\right)D\left(S\right)-C\left(S\right)D'\left(S\right)\leqslant 0.$$

Note $D'\left(S\right)=\frac{dD(S)}{dS}$ and $C'\left(S\right)=\frac{dC(S)}{dS}$. Rearranging the inequality and multiplying both sides by S, we can obtain

$$\frac{dD\left(S\right)}{D\left(S\right)}\frac{S}{dS}\geqslant\frac{dC\left(S\right)}{C\left(S\right)}\frac{S}{dS}.$$

According to Definition 3 and 4, we can obtain

$$\epsilon_{D,S}\geqslant\epsilon_{C,S},$$

where $\epsilon_{D,S}=\frac{dD(S)}{D(S)}\frac{S}{dS}$ is the safety elasticity of delay and $\epsilon_{C,S}=\frac{dC(S)}{C(S)}\frac{S}{dS}$ is the safety elasticity of cost.

Otherwise, $\overline{R}^{FB}$ decreases with safety levels S.

Moreover, the proof of $\underline{R}^{FB}$, $\overline{R}^{SB}$, and $\underline{R}^{SB}$ follows exactly the same way and is omitted henceforth. □

The intuition behind Proposition 2 is straightforward. According to the assumptions $D'\left(S\right)>0$ and $C'\left(S\right)>0$, the increases of safety levels will lead to longer delays and higher costs. Longer delays will motivate the regulator to choose higher degrees of the delay reduction service while higher costs will bring an opposite motivation for the regulator. Therefore, when the safety elasticity of delay is larger than the safety elasticity of cost, which implies that the effect of the increases of safety levels on delays is larger than those on costs, the motivation related to delays will dominate the one related to costs and thus the regulator will increase the optimal degrees of the delay reduction service. Otherwise, the motivation related to costs will dominate the one related to delays and thus the regulator will decrease the optimal degrees of the delay reduction service.

The result in Proposition 2 is helpful for the regulator about setting safety levels. From Proposition 2, we can see that, when $\epsilon_{D,S} < \epsilon_{C,S}$, the optimal degrees of the delay reduction service may be very small when safety level is too high, which implies that the new generation air traffic management system may be less efficiently used. Therefore, knowing this possible situation, to ensure the efficient use of the new management system, the regulator can avoid setting a too high safety level when $\epsilon_{D,S} < \epsilon_{C,S}$.

Finally, we will study the effects of the changes of the weights on the optimal degrees of the delay reduction service, which may provide some suggestions for the regulator about setting the weights. The result is given in Proposition 3.

Proposition 3. *Considering the effects of the changes of the weights on the optimal degrees of the delay reduction service,*

1. the change of λ_1 cannot create a direct incentive but can create an indirect one for the regulator to change $\overline{R}^{FB}$, $\underline{R}^{FB}$, and $\overline{R}^{SB}$;

2. the increase (resp. decrease) of λ_1 can create an incentive for the regulator to increase (resp. decrease) $\underline{R}^{SB}$;

3. the increase (resp. decrease) of λ_2 can create an incentive for the regulator to increase (resp. decrease) $\overline{R}^{FB}$, $\underline{R}^{FB}$, $\overline{R}^{SB}$, and $\underline{R}^{SB}$;

4. the increase (resp. decrease) of λ_3 can create an incentive for the regulator to decrease (resp. increase) $\overline{R}^{FB}$, $\underline{R}^{FB}$, $\overline{R}^{SB}$, and $\underline{R}^{SB}$.

Proof. For λ_1, under complete information, optimally, the regulator will set the transfers $\overline{T}$ and $\underline{T}$ exactly the same with the benefits the monopoly airline can enjoy from the delay reduction service $\overline{\theta} D(S)\alpha\left(\overline{R}\right)$ and $\underline{\theta} D(S)\alpha\left(\underline{R}\right)$ respectively. Then, in the objective function, λ_1 does not link directly to $\overline{R}$ and $\underline{R}$ any more and thus the change of λ_1 does not directly affect $\overline{R}^{FB}$ and $\underline{R}^{FB}$. Moreover, under incomplete information, in the objective function, λ_1 only links directly to the information rent of the airline with type $\overline{\theta}$, which is a function of $\underline{R}$, not $\overline{R}$. Therefore, the change of λ_1 also does not directly affect $\overline{R}^{SB}$. However, we should notice the constraint $\lambda_1 + \lambda_2 + \lambda_3 = 1$, which implies that the change of λ_1 will inevitably lead to the change of at least one of the other two weights λ_2 and λ_3. Therefore, we can say that the increase of λ_1 cannot create a direct incentive but can create an indirect one for the regulator to change $\overline{R}^{FB}$, $\underline{R}^{FB}$, and $\overline{R}^{SB}$.

Furthermore, as we have mentioned, under incomplete information, λ_1 links directly to the information rent of the airline with type $\overline{\theta}$, which is a function of $\underline{R}$. Obviously, we can find that the increase (resp. decrease) of λ_1 can help reduce (resp. raise) the expected information rent, which will thus incentivize the regulator to increase (resp. decrease) $\underline{R}^{SB}$.

For analyzing the effects of the changes of λ_2 and λ_3, let us take $\overline{R}^{FB}$ as an example. Under complete information, the following equation determines $\overline{R}^{FB}$, i.e.,

$$\left(\lambda_2\beta + \lambda_3\overline{\theta}\right) D\left(S\right) \alpha'\left(\overline{R}^{FB}\right) = \lambda_3 C\left(S\right). \tag{18}$$

From the regulator's perspective, the left-hand side is the marginal utility while the right-hand side is the marginal cost. Normalizing the marginal cost to $C\left(S\right)$, we can obtain

$$\left(\frac{\lambda_2}{\lambda_3}\beta + \overline{\theta}\right) D\left(S\right) \alpha'\left(\overline{R}^{FB}\right) = C\left(S\right).$$

The increase (resp. decrease) of λ_2 can help make the marginal utility larger (resp. smaller) than the marginal cost. Thus, to keep them equal, the regulator has incentive to increase (resp. decrease) $\overline{R}^{FB}$. However, the increase (resp. decrease) of λ_3 can help make the marginal utility smaller (resp. larger) than the marginal cost. Thus, to keep them equal, the regulator has incentive to decrease (resp. increase) $\overline{R}^{FB}$.

Besides, the analysis of the effects of the changes of λ_2 and λ_3 on $\underline{R}^{FB}$, $\overline{R}^{SB}$, and $\underline{R}^{SB}$ follows the same way as the example.[4] $\square$

Here, we should be careful that the changes of λ_1, λ_2, and λ_3 can only affect the regulator's incentive to change the optimal degrees of the delay reduction service, but cannot determine the final adjustments. Whether the

[4]Comparing with (18), the equation which determines $\underline{R}^{SB}$ contains a marginal information rent. In fact, due to the existence of the marginal information rent, the increase (resp. decrease) of λ_3 can create an additional incentive for the regulator to decrease (resp. increase) $\underline{R}^{SB}$.

regulator eventually adjusts R as we expect depends on the total effects of the changes of λ_1, λ_2, and λ_3. Let us take the increase of λ_2 and the change of $\overline{R}^{FB}$ as an example. According to Proposition 5, the increase of λ_2 can create an incentive for the regulator to increase $\overline{R}^{FB}$. However, because the regulator may also change λ_3, whether $\overline{R}^{FB}$ will finally increase is uncertain. When the ratio $\frac{\lambda_2}{\lambda_3}$ becomes higher, $\overline{R}^{FB}$ will increase. Otherwise, $\overline{R}^{FB}$ will decrease.

From Proposition 3 and the following analysis, we can obtain Corollary 2.

Corollary 2. *Given other parameters unchanged,*

1. when the ratio $\frac{\lambda_2}{\lambda_3}$ becomes higher (resp. lower), $\overline{R}^{FB}$, $\underline{R}^{FB}$, and $\overline{R}^{SB}$ will be larger (resp. smaller);

2. when the ratios $\frac{\lambda_1}{\lambda_3}$ and $\frac{\lambda_2}{\lambda_3}$ become higher (resp. lower) at the same time, $\underline{R}^{SB}$ will be larger (resp. smaller); otherwise, besides $\frac{\lambda_1}{\lambda_3}$ and $\frac{\lambda_2}{\lambda_3}$, the change of $\underline{R}^{SB}$ also depends on the β, v, and $\triangle\theta$.

Proof. Just as (18), we can also write the equations which determine $\underline{R}^{FB}$, $\overline{R}^{SB}$, and $\underline{R}^{SB}$. Dividing these equations by λ_3 on both sides, we can easily see the Corollary 2. Thus, the proof is omitted henceforth. □

In fact, the intuition of Corollary 2 has been shown in the proof of Proposition 3.

The results in Proposition 3 and Corollary 2 are helpful for the regulator about setting the weights. From Proposition 3 and Corollary 2, we can see that, when the regulator reduces the weights of the monopoly airline's profit and passenger surplus a lot, the optimal degrees of the delay reduction service may be very small, which implies that the new generation air traffic management system may be less efficiently used. Therefore, knowing this possible situation, to ensure the efficient use of the new management system, the regulator can avoid reducing the weights of the monopoly airline's profit and passenger surplus a lot.

3.3 Examples

In this part, we will study four examples to illustrate the results in Proposition 1 and Corollary 2.

Example 1. $(\lambda_1, \lambda_2, \lambda_3) = \left(\frac{1}{3}, \frac{1}{3}, \frac{1}{3}\right)$.

In this example, the regulator acts as a social planner and cares about the social welfare.

The optimum in this example, denoted by $\overline{R}_{123}^{FB}$, $\underline{R}_{123}^{FB}$, $\overline{R}_{123}^{SB}$, and $\underline{R}_{123}^{SB}$, are

$$\alpha'\left(\overline{R}_{123}^{FB}\right) = \frac{C(S)}{\left(\beta+\overline{\theta}\right)D(S)},\ \alpha'\left(\underline{R}_{123}^{FB}\right) = \frac{C(S)}{\left(\beta+\underline{\theta}\right)D(S)};$$

$$\alpha'\left(\overline{R}_{123}^{SB}\right) = \frac{C(S)}{\left(\beta+\overline{\theta}\right)D(S)},\ \alpha'\left(\underline{R}_{123}^{SB}\right) = \frac{C(S)}{\left(\beta+\underline{\theta}\right)D(S)}.$$

Example 2. $(\lambda_1, \lambda_2, \lambda_3) = \left(\frac{1}{2}, 0, \frac{1}{2}\right)$.

In this example, the regulator cares only about the sum of the monopoly airline's profit and its own profit but nothing about passenger surplus. In reality, this example does not likely exist because the regulator always places great emphasis on consumers. Here, we only discuss it theoretically.

The optimum in this example, denoted by $\overline{R}_{13}^{FB}$, $\underline{R}_{13}^{FB}$, $\overline{R}_{13}^{SB}$, and $\underline{R}_{13}^{SB}$, are

$$\alpha'\left(\overline{R}_{13}^{FB}\right) = \frac{C(S)}{\overline{\theta}D(S)},\ \alpha'\left(\underline{R}_{13}^{FB}\right) = \frac{C(S)}{\underline{\theta}D(S)};$$

$$\alpha'\left(\overline{R}_{13}^{SB}\right) = \frac{C(S)}{\overline{\theta}D(S)},\ \alpha'\left(\underline{R}_{13}^{SB}\right) = \frac{C(S)}{\underline{\theta}D(S)}.$$

Example 3. $(\lambda_1, \lambda_2, \lambda_3) = \left(0, \frac{1}{2}, \frac{1}{2}\right)$.

In this example, the regulator cares only about the sum of passenger surplus and its own profit but nothing about the monopoly airline's profit. This example is essentially an extreme one for the fact that sometimes the regulator cares more about consumers than firms.

The optimum in this example, denoted by $\overline{R}_{23}^{FB}$, $\underline{R}_{23}^{FB}$, $\overline{R}_{23}^{SB}$, and $\underline{R}_{23}^{SB}$, are

$$\alpha'\left(\overline{R}_{23}^{FB}\right) = \frac{C(S)}{\left(\beta+\overline{\theta}\right)D(S)},\ \alpha'\left(\underline{R}_{23}^{FB}\right) = \frac{C(S)}{\left(\beta+\underline{\theta}\right)D(S)};$$

$$\alpha'\left(\overline{R}_{23}^{SB}\right)=\frac{C(S)}{\left(\beta+\overline{\theta}\right)D(S)},\ \alpha'\left(\underline{R}_{23}^{SB}\right)=\frac{C(S)}{\{\beta+\underline{\theta}-[v/(1-v)]\triangle\theta\}D(S)}.$$

Example 4. $(\lambda_1,\lambda_2,\lambda_3)=(0,0,1)$.

In this example, the regulator cares only about its own profit but nothing about the monopoly airline's profit and passenger surplus. This example is similar to the models in some principal-agent literature, where the principal cares only about its own profit.

The optimum in this example, denoted by $\overline{R}_3^{FB}$, $\underline{R}_3^{FB}$, $\overline{R}_3^{SB}$, and $\underline{R}_3^{SB}$, are

$$\alpha'\left(\overline{R}_{3}^{FB}\right)=\frac{C(S)}{\overline{\theta}D(S)},\ \alpha'\left(\underline{R}_{3}^{FB}\right)=\frac{C(S)}{\underline{\theta}D(S)};$$

$$\alpha'\left(\overline{R}_{3}^{SB}\right)=\frac{C(S)}{\overline{\theta}D(S)},\ \alpha'\left(\underline{R}_{3}^{SB}\right)=\frac{C(S)}{\{\underline{\theta}-[v/(1-v)]\triangle\theta\}D(S)}.$$

Comparing the optimal degrees of the delay reduction service, under complete information, we obtain

$$\overline{R}_{123}^{FB}=\overline{R}_{23}^{FB}>\overline{R}_{13}^{FB}=\overline{R}_{3}^{FB},$$

$$\underline{R}_{123}^{FB}=\underline{R}_{23}^{FB}>\underline{R}_{13}^{FB}=\underline{R}_{3}^{FB}.$$

Under incomplete information, for the airline with type $\overline{\theta}$, with respect to the first-best, we can obtain

$$\overline{R}_{123}^{SB}=\overline{R}_{123}^{FB},\ \overline{R}_{13}^{SB}=\overline{R}_{13}^{FB},\ \overline{R}_{23}^{SB}=\overline{R}_{23}^{FB},\ \overline{R}_{3}^{SB}=\overline{R}_{3}^{FB}.$$

Moreover, we have

$$\overline{R}_{123}^{SB}=\overline{R}_{23}^{SB}>\overline{R}_{13}^{SB}=\overline{R}_{3}^{SB}.$$

For the airline with type $\underline{\theta}$, with respect to the first-best, we can obtain

$$\underline{R}_{123}^{SB}=\underline{R}_{123}^{FB},\ \underline{R}_{13}^{SB}=\underline{R}_{13}^{FB},\ \underline{R}_{23}^{SB}<\underline{R}_{23}^{FB},\ \underline{R}_{3}^{SB}<\underline{R}_{3}^{FB}.$$

Moreover, when $\frac{v}{1-v}\triangle\theta\leqslant\beta$, we have

$$\underline{R}_{123}^{SB}>\underline{R}_{23}^{SB}\geqslant\underline{R}_{13}^{SB}>\underline{R}_{3}^{SB};$$

when $\frac{v}{1-v} \triangle \theta > \beta$, we have

$$\underline{R}_{123}^{SB} > \underline{R}_{13}^{SB} > \underline{R}_{23}^{SB} > \underline{R}_{3}^{SB}.$$

To make the comparison easier to see, we show these optimal degrees of the delay reduction service in Figure 2 and 3.

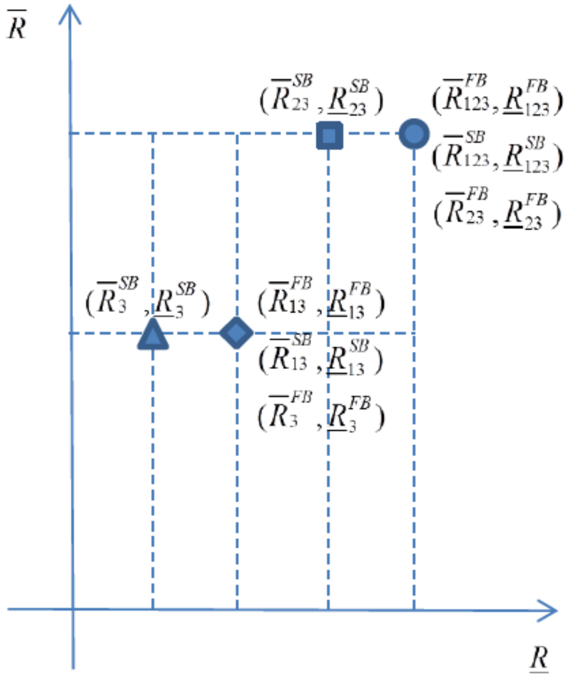

Figure 2: Optimal Degrees (when $\frac{v}{1-v} \triangle \theta \leqslant \beta$)

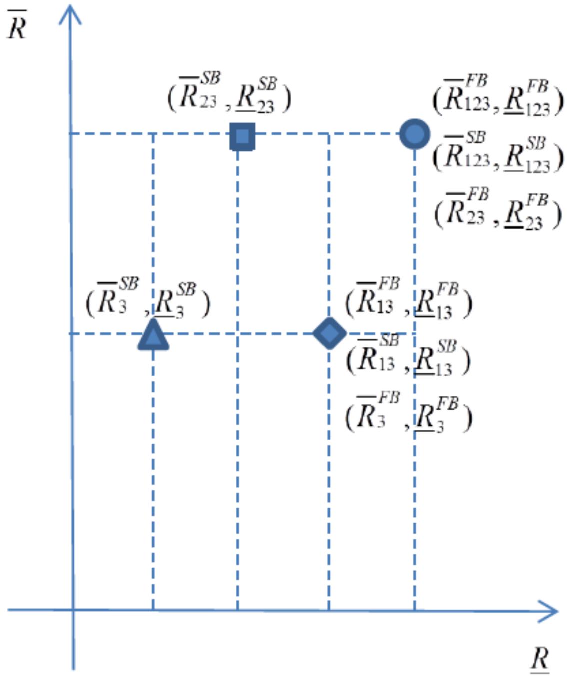

Figure 3: Optimal Degrees (when $\frac{v}{1-v} \bigtriangleup \theta > \beta$)

Then, we analyze the examples as follows.

First, from the comparison, we can see that, the more the regulator cares about the interests of the monopoly airline and passengers, the larger the optimal degree of the delay reduction service will be. Intuitively, we can explain it like this. Because the monopoly airline and passengers can enjoy benefits from the delay reduction service, they have a positive need for the service. Therefore, if the regulator cares more about the monopoly airline and passengers, optimally, it will increase the degree of the delay reduction service to satisfy their need.

Second, the examples illustrate the result in Proposition 1. For the airline with type $\overline{\theta}$, in every example, the second-best degree of the delay reduction service is equal to the first-best one. However, for the airline with type $\underline{\theta}$, in Example 3 and 4, the second-best one is smaller than the first-best one; in Example 1 and 2, the second-best one is equal to the first-best one. In fact, the comparison above is consistent with the result in Proposition 1, i.e., under incomplete information, with respect to the first-best, there is no distortion for the airline with type $\overline{\theta}$, while for the airline with type $\underline{\theta}$, there is a downward distortion when $\lambda_3 > \lambda_1$ and no distortion when $\lambda_3 = \lambda_1$.

Third, the examples also illustrate the result in Corollary 2. $\frac{\lambda_1}{\lambda_3} = \frac{\lambda_2}{\lambda_3} = 1$ in Example 1 are the highest ratios and we can see that $\overline{R}_{123}^{FB}$, $\underline{R}_{123}^{FB}$, $\overline{R}_{123}^{SB}$, and $\underline{R}_{123}^{SB}$ are the largest degrees. $\frac{\lambda_1}{\lambda_3} = \frac{\lambda_2}{\lambda_3} = 0$ in Example 4 are the lowest ratios and we can see that $\overline{R}_3^{FB}$, $\underline{R}_3^{FB}$, $\overline{R}_3^{SB}$, and $\underline{R}_3^{SB}$ are the smallest degrees. $\frac{\lambda_2}{\lambda_3} = 1$ in Example 3 is higher than $\frac{\lambda_2}{\lambda_3} = 0$ in Example 2 and we can see that $\overline{R}_{23}^{FB}$, $\underline{R}_{23}^{FB}$, and $\overline{R}_{23}^{SB}$ are larger than $\overline{R}_{13}^{FB}$, $\underline{R}_{13}^{FB}$, and $\overline{R}_{13}^{SB}$ respectively. Moreover, there are $\frac{\lambda_1}{\lambda_3} = 1$ and $\frac{\lambda_2}{\lambda_3} = 0$ in Example 2 and $\frac{\lambda_1}{\lambda_3} = 0$ and $\frac{\lambda_2}{\lambda_3} = 1$ in Example 3 and we can see that, besides $\frac{\lambda_1}{\lambda_3}$ and $\frac{\lambda_2}{\lambda_3}$, the comparison between $\underline{R}_{13}^{SB}$ and $\underline{R}_{23}^{SB}$ also depends on the passengers' value of time β and the degree of downward distortion $\frac{v}{1-v} \bigtriangleup \theta$. When the degree of downward distortion is relatively low, i.e., $\frac{v}{1-v} \bigtriangleup \theta \leqslant \beta$, we can see that $\underline{R}_{23}^{SB}$ is larger than $\underline{R}_{13}^{SB}$. However, when the degree of downward distortion is relatively high, i.e., $\frac{v}{1-v} \bigtriangleup \theta > \beta$, we can see that $\underline{R}_{23}^{SB}$ is smaller than $\underline{R}_{13}^{SB}$.

4 Conclusions and Policy Suggestions

Under the background of the Single European Sky program, this paper proposed a contract signed between the regulator and the monopoly airline to implement a delay reduction service. Different from previous literature, this paper used a new delay function, which was proposed in Wang (2013). Specifically, instead of the total number of flights and airport capacities, this paper only modeled safety levels into the delay function. Moreover, the regulator's objective function in this paper was a weighted sum of the monopoly airline's profit, passenger surplus, and the regulator's profit.

To reduce the delays caused mainly by safety consideration, we introduced a delay reduction service and proposed a contract in which the degree of the delay reduction service and the transfer are formulated. After deriving the optimal contracts, we compared the optimal degrees of the delay reduction service under complete and incomplete information. We found that, under incomplete information, for the airline with a high value of time, there was no distortion with respect to the first-best. However, for the airline with a low value of time, there was a downward distortion or no distortion with respect to the first-best, which depended on the weights of the regulator's profit and the monopoly airline's profit. Moreover, we also compared the optimal transfers under complete and incomplete information. Then, we showed that the optimal degrees of the delay reduction service increased with safety levels when the safety elasticity of delay was larger than the safety elasticity of cost and decreased with safety levels otherwise. Furthermore, we showed that the changes of the weights could create different incentives for the regulator to adjust the optimal degrees of the delay reduction service. Besides, we studied how the ratios of the weights determined the changes of the optimal degrees. In the last part, we studied four examples to illustrate some of the results above.

This paper is rather policy-oriented. Throughout the paper, there are four main policy suggestions as the following.

First, the regulator should be aware of the fact that, for the future European air transport industry, safety levels will become the most significant factor determining air traffic delays.

Second, the optimal contracts are incentive feasible and passengers can enjoy benefits from them. Therefore, it is worthwhile for the regulator to implement these optimal contracts.

Third, under incomplete information, by valuing equally its own profit and the monopoly airline's profit, the regulator can achieve the first-best contract except a lower transfer for the airline with a high value of time.

Fourth, the regulator should avoid setting a too high safety level when the safety elasticity of delay is smaller than the safety elasticity of cost. Moreover, the regulator should also avoid reducing the weights of the monopoly airline's profit and passenger surplus a lot. Otherwise, the new generation air traffic management system may be less efficiently used.

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