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Abstract: This paper focuses on the international transportation market in which a high-speed rail (HSR) firm competes with both the domestic and foreign airline firms providing differentiated transport services. We investigate and compare two types of corporate social responsibility (CSR)—mandatory and voluntary CSR—imposed on HSR under a government subsidy policy. We show that, when the transport substitutability is high (low) in a domestic travel leg, mandatory CSR is lower (higher) than voluntary CSR, and the optimal subsidy under mandatory CSR is lower (higher) than that under voluntary CSR. We also examine the effect of privatization policy of the HSR with transposition subsidy on welfare. We show that full privatization with CSR activities always improves social welfare under an appropriate subsidy, independent of the transport substitutability and types of CSR activities.

Keywords: High-speed rail, corporate social responsibility, transportation subsidy, privatization policy, mixed market

1. Introduction

China's high-speed rail (HSR) dramatically developed in the last two decades. The first HSR in China officially began operation in 2008, and China's HSR mileage has ranked first in the world since 2012. As the four north-south and four east-west corridors of the HSR network had almost been completed, the government proposed the eight north-south and eight east-west corridors project in 2016. As a result, the coverage of China's HSR amazingly reached 38,000 km in 2020, adding up to two-thirds of the total coverage of the world's HSR. In recent times, HSR has become a popular mode of transport in China and is also an alternative to air travel for medium and long-distance travel. In China, HSR

competes with airlines providing differentiated transport services over journeys of 400–800 km.[1]

Meanwhile, the regulatory reform for the HSR has progressed into a mixed economy, in which a state-owned HSR competes with private airlines in the passenger transportation market. In order to separate the functions of the government from those of enterprises, the government canceled the Ministry of Railways and carried out structural reforms in the railway industry in 2013.[2] Consequently, in 2019, to operate both the HSR and ordinal railways, China Railway Corporation was established and became in charge of raising funds during construction and setting ticket fares during operation. However, the government could indirectly regulate business ethics related to the corporate social responsibility (CSR) activities of the HSR firm.[3]That is, the HSR acts like a partially privatized firm under the government's indirect control of the well-being of consumers. As the central government gradually liberalized price controls, both the HSR and airlines can independently set their ticket fares, considering the fierce competition over fares and traffic volumes in the transportation market.

A debatable issue in the current deregulation of the HSR operator in China is whether CSR should be regulated, as activities of voluntary CSR are philanthropic.[4] This was done considering that the HSR operator was previously in a mixed economy and is presently viewed as a privatized firm under the government imposition of CSR. As firms and the government implement new initiatives to enforce CSR practices, it is critical to identify the type of relationship between voluntary CSR and legislated CSR.[5]

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[1] For more details, see Givoni (2005), Givoni and Banister (2007), Rothengatter (2011), Fu et al. (2012), and Socorro and Viecens (2013).

[2] For practical discussions in the liberalization period on the privatization and structural reform policies in Asian countries including Japan and South Korea, see Lee (2006) and Lee et al. (2018). Boubakri et al. (2019) evaluated 41 countries' links between privatization and CSR from 2002 to 2014. They found that the private firm have, on average, higher sense of CSR than the public firm.

[3] Previous studies examined the effect of both direct government ownerships and indirect modes on privatization. For example, the government can indirectly control strategic decisions of privatized firms by political connections; see Fan et al. (2007), Boubakri et al. (2013), and Chen et al. (2018). These studies showed that connected firms must comply with government policies because the government provides subsidies and preferential treatments. (Ma and Parish 2006; Liu et al. 2011; Khan et al 2020). Therefore, the politically loyal bureaucrats appointed on the board of privatized firms can help the remaining state owners to make decisions on CSRs.

[4] The global perception of CSR has evolved to current trends that start routing voluntary CSR towards legal CSR. It is common that that firms can voluntarily choose whether to assume social responsibilities because the law did not specify the standards of CSR (McWilliams and Siegel, 2001; Dahlsrud, 2008). However, some recent cases of legally compelling enterprises to fulfill their social responsibilities have questioned the view of voluntary CSR (Waagstein, 2011). Thus, as the government gradually formulates laws and regulations on CSR, the debate on the nature of CSRs continues. For example, Indonesia in 2007, Denmark in 2008, France in 2010, Philippines and Spain in 2011, Argentina and Brazil in 2012, India and Norway in 2013, and European Union in 2014. A completely revised Companies Act by the India government in 2013 marked a bold step in legalization of CSR. For more discussion, see Gatti et al. (2019) and Isaksson and Mitra (2019).

[5] Xu et al. (2020) examined the standard CSR and voluntary CSR in a domestic transportation market in which a

Therefore this paper addresses the questions of whether CSR should be voluntary or mandatory and whether privatization policy with CSR activities can improve social welfare under an appropriate government subsidy policy.

Initial studies on the transportation services markets in which the HSR competes with airlines were pioneered by Janic (1993), who examined the private firm's decisions on infrastructure investment over a single origin-destination link. In the domestic mixed market configuration in which the HSR is a partially privatized firm, Yang and Zhang (2012) examined the impact of HSR and airlines competition on firms' profits and social welfare, and D'Alfonso et al. (2015, 2016) investigated the impact of the HSR and airline competition on the environment. In particular, they showed that when the government owns a higher stake in the HSR firm, competitions between two modes of transport have a negative effect on the environment. Considering a three origin-destination link, Jiang and Zhang (2014) analyzed the impact of a capacity-constrained HSR and a hub-and-spoke airline cooperation in the domestic market. Jiang et al. (2017) also extended the analysis of air-rail cooperation into the international market in which the rail operator might cooperate with either domestic or foreign airlines. Finally, Xia et al. (2019) examined a revenue sharing mechanism between airline and HSR with retaining its own objective function in an international transport market.

However, there is limited research on strategic decisions on CSR of the HSR firm in an international differentiated transportation market, and the relationships between strategic CSR and government subsidy policy with reforms of state-owned enterprises. This paper examines a mandatory CSR policy enforced by law or regulation and determines the conditions under which voluntary CSR approach is more effective to implement and engage.

The contribution of this paper is three-fold. First, a theoretical model is used to discuss the two types of CSR imposed on the HSR with a variety of transport substitutability in an international market: mandatory CSR which is imposed by the government and voluntary CSR, which is chosen by the HSR operator. The transport substitutability is incorporated between the HSR and the airline in a domestic leg and also incorporated between domestic and foreign airlines in an international leg. Second, the relationship between types of CSR imposed on the HSR and transportation industry policy is

HSR engaged in CSR and a domestic airline compete in both prices and quantities with linear cost function.

investigated, leading to potential policy development. Particularly, the government provides transportation subsidies to both the HSR and domestic airline when competing with foreign airlines in an international differentiated market. It is necessary to carefully investigate the types of CSR imposed on the HSR when the government additionally provides an output subsidy to the domestic firms to increase their competitive advantage. Third, this paper investigates the effect of privatization policy of the HSR on welfare with various types of CSR activities and transport substitutability under a government subsidy policy in an open mixed economy. It would be beneficial to academia and industry to have a better understanding of the effect of privatization policy.

Here, we consider an international transportation market in which the HSR competes with airlines with differentiated services under government policies and investigates a strategic relationship between different CSR activities and transportation subsidy policy. The main results are as follows. First, the optimal subsidy is increasing in transport substitutability between HSR and airline, while it is decreasing in transport substitutability between airlines. However, the effect of transport substitutability on strategic CSR depends on the types of CSR. Second, the relationship between CSR activities and transportation subsidy depends on transport substitutability. In particular, when the transport substitutability in the domestic leg is low, mandatory CSR can be higher than voluntary CSR, and the optimal subsidy under mandatory CSR is higher than that under voluntary CSR. The opposite results can be found when the transport substitutability in the domestic leg is high. Third, the full privatization of the HSR, in addition to CSR activities, always improves social welfare under an appropriate subsidy policy, which is independent of the type of CSR activities and transport substitutability. Alternatively, the effect of privatization policy with CSR activities on profits depends on the type of firm. It always increases the domestic firms' profits, while it decreases the foreign firms' profits, which is independent of the type of CSR activities and transport substitutability. Thus, domestic and foreign firms have different preferences for government regulations on state-owned HSR. Both the government and domestic firms will be better off if the privatization policy with CSR activities is implemented, while the foreign airline will be worse off.

The paper is organized as follows. The basic model is provided in Section 2, in which a HSR engaged in CSR activities competes with a domestic airline in a domestic leg, and the domestic airline

firm also competes with a foreign airline firm in an international leg. Section 3 analyses two scenarios in the international transportation market, namely mandatory CSR which is imposed by the government, and voluntary CSR which is chosen by the HSR operator. Section 4 compares the main results of the two scenarios and considers a comparable mixed market in which a state-owned HSR competes with airlines, and then examines the welfare effect of privatization of the HSR under government subsidy. Section 5 offers the conclusions to the paper.

2. The model

Suppose there is a connecting market, including a domestic leg and an international leg. Three firms compete in this transportation market: a domestic HSR firm, a domestic airline firm, and a foreign airline firm. We assume that the HSR services only the domestic leg, the foreign airline services only the international leg, while the domestic airline services two legs. Figure 1 represents the setting. In particular, N_1 is a peripheral city within the country, N_2 is a domestic hub used by domestic airlines as a gateway to the outside world. N_3 represents an international hub, or a collection of such international hubs, with the presence of both the domestic and foreign airlines. For example: N_1 represents a peripheral Chinese city, Dalian, N_2 is Beijing, its capital, and N_3 is Paris. The domestic airline firm is Air China, and the foreign airline firm is Air France.

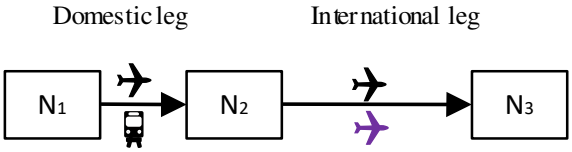

Figure1. Network structure

There are two origin-destination (OD) markets with the three cities: N_1N_2 and N_2N_3. As indicated above, the N_1N_2 market is a HSR-accessible market, which is operated by HSR and domestic airline. We denote q_{1R} and q_{1A} as the traffic volume of the HSR and domestic airline in market N_1N_2, respectively. The N_2N_3 market is a HSR-inaccessible market, which is operated by domestic and foreign airlines. We denote q_{2A} and q_{2F} as the traffic volume of the domestic and foreign airlines in market N_2N_3, respectively. Furthermore, the two modes of transport imperfectly substitute each other in the two legs, where $b_i \in (0,1)$ denotes the degree of transport substitutability. In particular, larger values of

b_i represent higher substitutability or lower differentiation, where $i = 1, 2$. Thus, higher substitutability reduces the passenger's willingness to pay, while it improves consumer surplus. Additionally, the parameter α_i represents a market size, where $i = 1, 2$. For the convenience of analysis without the loss of generality, we assume that two markets have the same market size with the following linear inverse demand functions in each market:

$$P_{1R} = \alpha - q_{1R} - b_1 q_{1A},$$
$$P_{1A} = \alpha - q_{1A} - b_1 q_{1R},$$
$$P_{2A} = \alpha - q_{2A} - b_2 q_{2F},$$
$$P_{2F} = \alpha - q_{2F} - b_2 q_{2A}, \quad (1)$$

where P_{1R} and P_{1A} respect the ticket fare of the HSR and domestic airline in market N_1N_2, and P_{2A} and P_{2F} respect the ticket fare of the domestic and foreign airline in market N_2N_3, respectively.

The cost function of each operator in the two markets is identical and increasing in its total quantities. In particular, $C_k(q_k) = \frac{1}{2}{q_k}^2$ for a single service provider where $k = 1R,\ 2F$, while $C_A(q_{1A} + q_{2A}) = \frac{1}{2}(q_{1A} + q_{2A})^2$ for domestic airline firm, which is a double services provider. Thus, the domestic airline firm has both diseconomies of scale and scope. We also assume that the government provides a transportation subsidy s per unit of output to the two domestic firms. The profits of the three firms are given by

$$\pi_R = (P_{1R} + s)q_{1R} - \frac{1}{2}{q_{1R}}^2,$$
$$\pi_A = (P_{1A} + s)q_{1A} + (P_{2A} + s)q_{2A} - \frac{1}{2}(q_{1A} + q_{2A})^2,$$
$$\pi_F = P_{2F}q_{2F} - \frac{1}{2}{q_{2F}}^2. \quad (2)$$

The consumer surplus is given by[6]

$$CS = \frac{1}{2}(q_{1A}^2 + q_{1R}^2 + 2b_1 q_{1A}q_{1R} + q_{2A}^2 + q_{2F}^2 + 2b_2 q_{2A}q_{2F}). \quad (3)$$

The social welfare is the sum of domestic industry profits and consumer surplus minus subsidy expenditures:

[6] Note that the demands of the two markets are independent and thus, the consumer surplus is separable, that is, $CS = CS_1 + CS_2$ where $CS_i = (q_{iA}^2 + q_{iR}^2 + 2b_i q_{iA}q_{iR})/2$ and $i = 1, 2$.

$$W = \pi_A + \pi_R + CS - s(q_{1R} + q_{1A} + q_{2A}). \quad (4)$$

Regarding the objective function of the three firms, we assume that both the domestic and foreign airlines seek to maximize profits, while the HSR pursuits not only profitability but also CSR activities. Then, the objective function of the HSR is:[7]

$$V = \pi_R + \beta CS, \quad (5)$$

where $\beta \in [0,1]$ denotes the degree of CSR of the HSR. Particularly, $\beta = 0$ means that the domestic HSR has no care about passengers' well-being.

Regarding the organizational structure of the HSR firm, we employ a managerial delegation framework where the owner and the operator are separated. However, the operator determines the optimal degree of CSR as an incentive contract.[8] In particular, we consider the two scenarios where either the government can impose mandatory CSR or the HSR operator can impose voluntary CSR. In the former case, when the state-owned HSR is privatized, the board members of the HSR firm are public officers who care for social welfare. In the latter case, the HSR is fully privatized without government regulation, and the operator decides the profit-maximizing degree of CSR. Therefore, we can compare mandatory CSR chosen by the welfare-maximizing government and voluntary CSR, which is chosen by the profit-maximizing HSR operator.

The order of the game is constructed as follows. In the first stage, the government decides the level of subsidy to maximize social welfare. In the second stage, taking the level of subsidy as given, either the government or the HSR operator chooses the degree of CSR to maximize their objectives, respectively. In the final stage, taking the level of subsidy and degree of CSR as given, the HSR and airlines compete in traffic volumes. The subgame perfect Nash equilibrium is solved by backward induction.

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[7] Note that if we consider a consumer surplus in N_1N_2 market that only the HSR addresses, then it takes care of a portion of CSR, that is, CS_1 instead of CS. Then, we have $V = \pi_R + \beta CS_1$. However, the analysis is the same because the demands of the two markets are independent and the consumer surplus is separable.

[8] From the perspective of shareholders, CSR is a business strategy which reflects the management's incentive contracts. For more discussion on the delegation framework where the CSR level is chosen by the firm directly involved, refer studies by Lambertini and Tampieri (2015), Leal et al. (2018), Kim et al. (2019), and Lee and Park (2019). Some works also considered other cases; for example, Liu et al. (2015) examined the strategic environmental CSR which is determined by NGOs, Brand and Grothe (2015) considered an upstream monopoly in a vertical relation, and Xu and Lee (2019) investigated mandatory CSR by a government in international trade.

3. The analysis

3.1. Output competition

In the final stage, the HSR operator chooses the traffic volume q_{1R} to maximize the objective function *V* in Eq. (5), the domestic airline operator chooses traffic volumes q_{1A} and q_{2A} to maximize its profit π_A in Eq. (2), and the foreign airline operator chooses the traffic volume q_{2F} to maximize its profit π_F in Eq. (2), respectively. The first-order conditions are

$$\frac{\partial V}{\partial q_{1R}} = s + \alpha - b_1 q_{1A} - 3q_{1R} + \beta(b_1 q_{1A} + q_{1R}) = 0,$$

$$\frac{\partial \pi_A}{\partial q_{1A}} = \mathrm{s} + \alpha - 3q_{1A} - q_{2A} - b_1 q_{1R} = 0,$$

$$\frac{\partial \pi_A}{\partial q_{2A}} = s + \alpha - q_{1A} - 3q_{2A} - b_2 q_{2F} = 0,$$

$$\frac{\partial \pi_F}{\partial q_{2F}} = \alpha - b_2 q_{2A} - 3q_{2F} = 0. \quad (6)$$

Solving Eq. (6), the traffic volumes of the three firms are derived as

$$q_{1R} = \frac{3(s+\alpha)(b_2^2-8)-(1-\beta)b_1((s+\alpha)b_2^2-6(s+\alpha)-\alpha b_2)}{(1-\beta)b_1^2(9-b_2^2)-3(3-\beta)(8-b_2^2)},$$

$$q_{1A} = \frac{(s+\alpha)b_1(9-b_2^2)+(3-\beta)((s+\alpha)b_2^2-6(s+\alpha)-\alpha b_2)}{(1-\beta)b_1^2(9-b_2^2)-3(3-\beta)(8-b_2^2)},$$

$$q_{2A} = \frac{\alpha(9-3\beta-(1-\beta)b_1^2)b_2-3(s+\alpha)(6-2\beta+b_1-(1-\beta)b_1^2)}{(1-\beta)b_1^2(9-b_2^2)-3(3-\beta)(8-b_2^2)},$$

$$q_{2F} = \frac{(s+\alpha)b_1b_2-2(3-\beta)(4\alpha-(s+\alpha)b_2)-(1-\beta)b_1^2((s+\alpha)b_2-3\alpha)}{(1-\beta)b_1^2(9-b_2^2)-3(3-\beta)(8-b_2^2)}. \quad (7)$$

Note that the effect of the transportation subsidy on traffic volumes depends on the type of firm. In particular, the subsidy increases the domestic firm's traffic volumes, while it decreases the foreign firm's traffic volumes, that is, $\frac{\partial q_{1R}}{\partial s} > 0$, $\frac{\partial q_{1A}}{\partial s} > 0$, $\frac{\partial q_{2A}}{\partial s} > 0$, and $\frac{\partial q_{2F}}{\partial s} < 0$. Note also that the effect of the CSR activities of the HSR on traffic volumes depends on the type of firm and market. In particular, the CSR activities of the HSR increase its traffic volumes, while they decrease the competitor's traffic volumes in a domestic leg, that is, $\frac{\partial q_{1R}}{\partial \beta} > 0$ and $\frac{\partial q_{1A}}{\partial \beta} < 0$. However, the CSR activities of the HSR increase the traffic volumes of the domestic airline, while they decrease the traffic volumes of the foreign airline in an international leg, that is, $\frac{\partial q_{2A}}{\partial \beta} > 0$ and $\frac{\partial q_{2F}}{\partial \beta} < 0$.

The profit of the HSR operator and social welfare are as follows[9]

$$\pi_R = \frac{\begin{matrix}(3(s+\alpha)(b_2^2-8)-(1-\beta)b_1((s+\alpha)b_2^2-6(s+\alpha)-\alpha b_2))(2(s+\alpha)\beta b_1^2(b_2^2-9)\\ -3(s+\alpha)(3-2\beta)(8-b_2^2)-(3+\beta)b_1((s+\alpha)b_2^2-6(s+\alpha)-\alpha b_2))\end{matrix}}{2((1-\beta)b_1^2(9-b_2^2)-3(3-\beta)(8-b_2^2))^2},$$

$$W = \frac{\begin{matrix}8(\alpha^2(765-462\beta+53\beta^2)+18s\alpha(17-14\beta+\beta^2)-9s^2))-2(1-\beta)b_1^3A_1-2b_1A_2\\ +(1-\beta)^2b_1^4(9(5\alpha^2+2s\alpha-2s^2)+6(s-2\alpha)\alpha b_2+(s^2-4s\alpha-7\alpha^2)b_2^2+2\alpha^2b_2^3)+b_1^2A_3+2b_2A_4\end{matrix}}{2((1-\beta)b_1^2(9-b_2^2)-3(3-\beta)(8-b_2^2))^2}. \quad (8)$$

Next, we analyze two scenarios in the international transportation market: mandatory CSR and voluntary CSR.

3.2. Mandatory CSR

We first consider mandatory CSR as the government's standard in which the degree of CSR, β, is chosen by a welfare-maximizing government in the second stage. Assuming interior solution, the differentiation of W in Eq. (8) with respect to β yields:

$$\beta = \frac{\begin{matrix}9(\alpha-2s)\left(8-b_2^2\right)^2-b_1^3(9(7s+\alpha)+3\alpha b_2-(17s+2\alpha)b_2^2+sb_2^4)+3b_1(60s-84\alpha-10\alpha b_2\\ +(25\alpha-17s)b_2^2+2\alpha b_2^3+(s-2\alpha)b_2^4)+b_1^2(306s+90\alpha-(71s+20\alpha)b_2^2+(4s+\alpha)b_2^4)\end{matrix}}{A_5}. \quad (9)$$

Note that the subsidy decreases the level of CSR, that is, $\frac{\partial \beta}{\partial s} < 0$. The government subsidy policy and CSR activities are substitutes in the international transportation market under mandatory CSR.

In the first stage, the government maximizes social welfare to decide the level of subsidy. Substituting Eq. (9) into Eq. (8), we obtain the resulting social welfare. Then, the differentiation of *W* with respect to *s* yields the following optimal subsidy:

$$s^M = \frac{\alpha(3b_1^2(3-b_2)(3+2b_2)+b_1(36-11b_2^2+b_2^4)-2(72+(1-b_2)b_2(20-b_2^2)))}{A_6}, \quad (10)$$

where the superscript "M" denotes the equilibrium outcome under **M**andatory CSR. Note that $0 < s^M < 1$. The government will always provide a transportation subsidy to domestic firms in an international differentiated market. Note also that the optimal subsidy is decreasing in b_1, while it is increasing in b_2, that is, $\frac{\partial s^M}{\partial b_1} < 0$ and $\frac{\partial s^M}{\partial b_2} > 0$. When the domestic airline and HSR perfectly substitute in a domestic leg, the government chooses a lower level of subsidy to decrease the output-improving effect of subsidy policy. Alternatively, when the domestic and foreign airlines are perfect

[9] The value of A_i where $i = 1, \dots, 13$ is provided in Appendix A.

substitutes in an international leg, the government chooses a higher subsidy to improve the competitive advantage of the domestic airline. Thus, the effects of transport substitutability on optimal subsidy depend on its extent in the domestic and foreign legs.

Substituting Eq. (10) into Eq. (9), the strategic mandatory CSR is

$$\beta^M = \frac{72-40b_2+2b_2^3-b_1^3(3-b_2)(3+2b_2)+9b_1^2(6+b_2-b_2^2)-b_1(36+(1-b_2)b_2(5+b_2))}{A_7}. \quad (11)$$

The strategic mandatory CSR is partial, that is, $0 < \beta^M < 1$. Thus, when the government provides an output subsidy in the first stage, it also makes the HSR participate in CSR activates. Further, the relationship between the strategic mandatory CSR and b_1 is U-shaped, while it is decreasing in b_2, that is, $\frac{\partial \beta^M}{\partial b_1} \lessgtr 0$ when b_1 is small (large) and $\frac{\partial \beta^{\mathrm{M}}}{\partial b_2} < 0$.[10]

The resulting traffic volumes of the firms at equilibrium are

$$q_{1R}^M = \frac{\alpha(b_1(72+b_2(11-b_2(17+(1-b_2)b_2)))-2(108-20b_2^2+b_2^4))}{A_6},$$

$$q_{1A}^M = \frac{\alpha(b_1^2(9+(3-2b_2)b_2)+b_1(90-17b_2^2+b_2^4)-2(72+b_2(14-b_2(18+(1-b_2)b_2))))}{A_6},$$

$$q_{2A}^M = \frac{\alpha(b_1^2(45-b_2(11+(3-b_2)b_2))-18b_1-4(36-b_2(11+(3-b_2)b_2)))}{A_6},$$

$$q_{2F}^M = \frac{\alpha(6b_1b_2-4(3-b_2)(12-b_2^2)+b_1^2(39-b_2(15+(3-b_2)b_2)))}{A_6}. \quad (12)$$

A few remarks are in order. First, the relationship between the HSR's traffic volume and b_1 is U-shaped, while the HSR's traffic volume is decreasing in b_2, that is, $\frac{\partial q_{1R}^M}{\partial b_1} \lessgtr 0$ when $b_1 \lessgtr A_8/A_9$ and $\frac{\partial q_{1R}^M}{\partial b_2} < 0$. Second, the domestic airline's traffic volume is decreasing in b_1, while it is increasing in b_2 in the N_1N_2 market, that is, $\frac{\partial q_{1A}^M}{\partial b_1} < 0$ and $\frac{\partial q_{1A}^M}{\partial b_2} > 0$. The opposite results could be found in the N_2N_3 market, that is, $\frac{\partial q_{2A}^M}{\partial b_1} > 0$ and $\frac{\partial q_{2A}^M}{\partial b_2} < 0$. Finally, the foreign airline's traffic volume is always decreasing in b_i, that is, $\frac{\partial q_{2F}^M}{\partial b_i} < 0$ where $i = 1, 2$.

The profits of the firms are

$$\pi_R^M = \frac{\alpha^2(b_1(72+11b_2-17b_2^2-b_2^3+b_2^4)-2(108-20b_2^2+b_2^4))(18b_1^2(6+b_2-b_2^2)-504}{2A_6{}^2},$$
$$\frac{-2b_1^3(3-b_2)(3+2b_2)-2b_2(2-3b_2)(20-b_2^2)+b_1(144+23b_2-43b_2^2-b_2^3+3b_2^4))}{2A_6{}^2},$$

[10] Derivative of b_i with respect to β, q_{1R} and π_R in the two scenarios are provided in Figures 2–4 in Appendix B.

$$\pi_A^M = \frac{\alpha^2(4(41472-4608b_2-12400b_2^2+480b_2^3+1624b_2^4+16b_2^5-109b_2^6-2b_2^7+3b_2^8) + b_1^4(7128-2736b_2-828b_2^2+476b_2^3-9b_2^4-22b_2^5+3b_2^6)+A_{10})}{2A_6{}^2},$$

$$\pi_F^M = \frac{3\alpha^2(6b_1b_2-4(3-b_2)(12-b_2^2)+b_1^2(39-b_2(15+(3-b_2)b_2)))^2}{2A_6{}^2}. \quad (13)$$

Note that the profit of the three firms are always decreasing in b_i, that is, $\frac{\partial \pi_R^M}{\partial b_i} < 0$, $\frac{\partial \pi_A^M}{\partial b_i} < 0$, and $\frac{\partial \pi_F^M}{\partial b_i} < 0$ where $i = 1, 2$. Thus, all three firms earn less when transport substitutability is high. In other words, the HSR could never be beneficial by increasing transport substitutability either in a domestic leg or in an international leg.

The resulting social welfare is

$$W^M = \frac{\alpha^2(2b_2(16+47b_2-2b_2^2-2b_2^3)-552+b_1^2(67-16b_2-7b_2^2+2b_2^3)+2b_1(72+11b_2-17b_2^2-b_2^3+b_2^4))}{2A_6}. \quad (14)$$

Note that social welfare is always decreasing in b_i, that is, $\frac{\partial W^M}{\partial b_i} < 0$ where $i = 1, 2$. Thus, society is worse off when the transport substitutability is high either in a domestic leg or in an international leg.

3.3. Voluntary CSR

The case of voluntary CSR is considered next, where β is determined by the profit maximizing HSR operator in the second stage. Assuming interior solution, the differentiation of π_R in Eq. (8) with respect to β yields

$$\beta = \frac{b_1^2(9-b_2^2)(6(s+\alpha)(4-b_1)-\alpha b_1 b_2-(s+\alpha)(3-b_1)b_2^2)}{9(s+\alpha)(8-b_2^2)^2+b_1(6s+6\alpha+\alpha b_2-sb_2^2-\alpha b_2^2)(48-9b_1^2-6b_2^2+b_1^2b_2^2)-3b_1^2(s+\alpha)(72-17b_2^2+b_2^4)}. \quad (15)$$

Note that the subsidy increases the level of CSR, that is, $\frac{\partial \beta}{\partial s} > 0$. In other words, the government subsidy policy and CSR activities complement each other in the international transportation market under voluntary CSR, which is opposite to the result under mandatory CSR.

Substituting Eq. (15) into Eq. (8), we can get social welfare. In the first stage, the differentiation of W with respect to s yields

$$s^V = \frac{\alpha(81(8-b_2^2)^2(136+20b_2-36b_2^2-b_2^3+2b_2^4)-54b_1(8-b_2^2)^2(84+5b_2-25b_2^2-b_2^3+2b_2^4)+b_1^4(3-b_2)(3672+2844b_2-552b_2^2-522b_2^3-20b_2^4+5b_2^5+4b_2^6+2b_2^7)-9b_1^2(8-b_2^2)(2880+624b_2-1046b_2^2-83b_2^3+109b_2^4+b_2^5-3b_2^6)+3b_1^3(8-b_2^2)(2808+162b_2-1164b_2^2-53b_2^3+166b_2^4+4b_2^5-8b_2^6))}{A_{11}}, \quad (16)$$

where the subscript "V" denotes the equilibrium outcome under **V**oluntary CSR. Note that $0 < s^V < 1$.

Thus, the government will always provide a transportation subsidy to domestic firms in an international differentiated market under mandatory CSR. Note also that the optimal subsidy is increasing in b_1, while it is decreasing in b_2, that is, $\frac{\partial s^V}{\partial b_1} < 0$ and $\frac{\partial s^V}{\partial b_2} > 0$.

Substituting Eq. (16) into Eq. (15), the strategic voluntary CSR is

$$\beta^V = \frac{(b_1^2(9-b_2^2)(b_1^3(1080+222b_2-360b_2^2-35b_2^3+36b_2^4+b_2^5-b_2^6)-b_1^2(2592+84b_2-468b_2^2+31b_2^3-6b_2^4 \\ -5b_2^5+3b_2^6)+9(8-b_2^2)(480+20b_2-108b_2^2-b_2^3+6b_2^4)-3b_1(8-b_2^2)(648+68b_2-180b_2^2-7b_2^3+12b_2^4))}{A_{12}}. \quad (17)$$

The strategic voluntary CSR is partial, that is, $0 < \beta^V < 1$. Thus, when the government provides an output subsidy in the first stage, the HSR with voluntary CSR will always decides to participate in CSR. In addition, voluntary CSR is increasing in b_1, while the relationship between voluntary CSR and b_2 is inversely U-shaped, that is, $\frac{\partial \beta^V}{\partial b_1} > 0$ and $\frac{\partial \beta^V}{\partial b_2} \gtrless 0$ when b_1 is small (large). A higher level of substitutability between the HSR and domestic airline yields a fiercer market competition in the domestic leg. Additionally, the HSR chooses a higher voluntary CSR to serve more passengers under quantity competition. Alternatively, the effect of b_2 on optimal voluntary CSR depends on b_1. When the market competition in the domestic leg is less fierce, an increase in substitutability between airlines increases the optimal level of voluntary CSR, otherwise, the opposite results are found.

Next, we consider the equilibrium traffic volumes, profits, and welfare under voluntary CSR. First, the relationship between the HSR's traffic volume and b_1 is U-shaped, while the relationship between the HSR's traffic volume and b_2 is inversely U-shaped, that is, $\frac{\partial q_{1R}^V}{\partial b_1} \lessgtr 0$ and $\frac{\partial q_{1R}^V}{\partial b_2} \gtrless 0$. Second, the domestic airline's traffic volume in N_1N_2 market is decreasing in b_1, while it is increasing in b_2, that is, $\frac{\partial q_{1A}^V}{\partial b_1} < 0$ and $\frac{\partial q_{1A}^V}{\partial b_2} > 0$. The opposite results are found when the domestic airline competes with the foreign airline in N_2N_3 market, that is, $\frac{\partial q_{2A}^V}{\partial b_1} > 0$ and $\frac{\partial q_{2A}^V}{\partial b_2} < 0$. Third, the foreign airline's traffic volume is always decreasing in b_i, that is, $\frac{\partial q_{2F}^V}{\partial b_i} < 0$ where $i = 1, 2$.

Further, the HSR's profit is decreasing in b_1, while the relationship between the HSR's profit and b_2 is inversely U-shaped, that is, $\frac{\partial \pi_R^V}{\partial b_1} < 0$ and $\frac{\partial \pi_R^V}{\partial b_2} \gtrless 0$. Alternatively, the airlines' profits are always decreasing in b_i, that is, $\frac{\partial \pi_A^V}{\partial b_i} < 0$ and $\frac{\partial \pi_F^V}{\partial b_i} < 0$ where $i = 1, 2$. Finally, social welfare is always

decreasing in b_i, that is, $\frac{\partial W^V}{\partial b_i} < 0$ where $i = 1, 2$.

4. Comparison and discussion

4.1. Comparison

Proposition 1: *Under transportation subsidy, mandatory CSR is higher (lower) than voluntary CSR when the transport substitutability in the domestic leg is low (high).*

Proof: Comparing the optimal degrees of the CSR in Eqs. (11) and (17) in the two scenarios,[11] we have $\beta^M \gtrless \beta^V$, depending on whether b_1 is small or large.

Proposition 1 states that the transport substitutability is critical to the relationship between mandatory CSR and voluntary CSR when the government provides a subsidy to domestic firms. On the one hand, voluntary CSR is lower than mandatory CSR when the transport competition is fierce in the domestic leg. That is, the HSR operator will choose a lower voluntary CSR when the transport substitutability between HSR and airline is low. On the other hand, higher transport substitutability makes the HSR operator voluntarily delegate higher CSR to managers to expand productions, thereby resulting in over-production in the market, and thus urging the government to enforce a lower level of mandatory CSR.

Proposition 2: *The optimal subsidy under mandatory CSR is lower (higher) than that under voluntary CSR when the transport substitutability in a domestic leg is low (high).*

Proof: Comparing the optimal levels of the subsidy in Eqs. (10) and (16) in the two scenarios, we have $s^M \lessgtr s^V$, depending on whether b_1 is small or large.

Proposition 2 states that mandatory CSR should be accompanied by a lower subsidy than voluntary CSR when the transport competition is fierce in a domestic leg. This is because mandatory CSR is a firm-specific regulation while output subsidy is an industry-wide regulation for the domestic firms.

[11] Numerical comparisons of the main results in the two models are provided in Figure 5 in Appendix B.

From proposition 1, when the competition between HSR and airline is fierce in the domestic leg, mandatory CSR can be lower than voluntary CSR, which might decrease total market production. Thus, the government should increase the level of subsidy to domestic firms. That is, the government increases the product-improving effect of the subsidy policy when it could simultaneously choose the mandatory CSR. However, when the transport competition between HSR and airline is less fierce, the government will provide a lower subsidy to domestic firms. In comparison, it imposes a higher mandatory CSR on the HSR.

Proposition 3: *Mandatory CSR might yield lower profits for the domestic firms and higher profits for the foreign firm than voluntary CSR, and mandatory CSR always yields higher social welfare than voluntary CSR.*

Proof: Comparing the equilibrium profits of the firm and social welfares in the two scenarios, we have (i) ${\pi_R}^M \lessgtr {\pi_R}^V$, ${\pi_A}^M \lessgtr {\pi_A}^V$, and ${\pi_F}^M \gtrless {\pi_F}^V$, depending on b_1 whether it is small or large; (ii) $W^M > W^V$.

Proposition 3 states that the effect of voluntary CSR on profits depends on the type of firm when the government provides a transportation subsidy to domestic firms. Particularly, domestic firms are better off with voluntary CSR in an extensive range. At the same time, they are worse off with voluntary CSR only when the transport substitutability is extremely high in both the domestic and foreign legs. The opposite results could be found for the foreign firm. Proposition 3 also states that social welfare under mandatory CSR is higher than voluntary CSR when the government provides a transportation subsidy. The society is better off with mandatory CSR. Thus, the local government and domestic firms may have different preferences on CSR under transportation subsidy. The local government prefers mandatory CSR. In contrast, both HSR and airline firms prefer voluntary CSR.

4.2. The welfare effect of privatization policy

We consider a mixed transportation market situation in which a state-owned HSR competes with two profit-maximizing airlines. Note that the government fully owns the HSR, and it seeks welfare-maximization when engaging in CSR activities nor providing an output subsidy, that is, $\beta = s = 0$.

In the final stage, the government decides the traffic volume q_{1R} to maximize social welfare in Eq. (4). The first-order condition is

$$\frac{\partial W}{\partial q_{1R}} = \alpha - 2b_1 q_{1A} - 3q_{1R} + b_1 q_{1A} + q_{1R} = 0. \tag{18}$$

Solving Eq. (6) and Eq. (18), the traffic volumes of the three firms are derived as

$$q_{1R}^B = \frac{\alpha(24-3b_2^2-b_1(3-b_2)(2+b_2))}{48-9b_1^2-(6-b_1^2)b_2^2},$$

$$q_{1A}^B = \frac{\alpha(b_2-3)(b_1(3+b_2)-2(2+b_2))}{48-9b_1^2-(6-b_1^2)b_2^2},$$

$$\mathrm{q}_{2A}^B = \frac{\alpha(b_1(3-b_1(3-b_2))+6(2-b_2))}{48-9b_1^2-(6-b_1^2)b_2^2},$$

$$\mathrm{q}_{2F}^B = \frac{\alpha(16-3b_1^2-(4+(1-b_1)b_1)b_2)}{48-9b_1^2-(6-b_1^2)b_2^2}. \tag{19}$$

where the subscript "B" denotes the equilibrium outcome in a **B**enchmark case for privatization policy. First, the relationship between the HSR's traffic volume and b_1 is U-shaped, while the HSR's traffic volume is always decreasing in b_2, that is, $\frac{\partial q_{1R}^B}{\partial b_1} \lessgtr 0$ when $b_1 \lessgtr A_{13}$ and $\frac{\partial q_{1R}^B}{\partial b_2} < 0$. Second, when the domestic airline competes with the HSR in the N_1N_2 market, the domestic airline's traffic volume is decreasing in b_1, while it is increasing in b_2, that is, $\frac{\partial q_{1A}^B}{\partial b_1} < 0$ and $\frac{\partial q_{1A}^B}{\partial b_2} > 0$. The opposite results are found when the domestic airline competes with the foreign airline in the N_2N_3 market, that is, $\frac{\partial q_{2A}^B}{\partial b_1} > 0$ and $\frac{\partial q_{2A}^B}{\partial b_2} < 0$. Finally, the foreign airline's traffic volume is always decreasing in b_i, that is, $\frac{\partial q_{2F}^B}{\partial b_i} < 0$.

The ticket fares of the firms are respectively:

$$P_{1R}^B = \frac{\alpha(24-3b_2^2-b_1(3-b_2)(2+b_2))}{48-9b_1^2-(6-b_1^2)b_2^2},$$

$$P_{1A}^B = \frac{\alpha(3(12-b_1(5+b_1))-(2-b_1^2)b_2-2(2-b_1)b_2^2)}{48-9b_1^2-(6-b_1^2)b_2^2},$$

$$P_{2A}^B = \frac{\alpha(2b_1^2(b_2-3)+b_1(b_2^2-3)+2(18-b_2(5+b_2)))}{48-9b_1^2-(6-b_1^2)b_2^2},$$

$$P_{2F}^B = \frac{2\alpha(16-3b_1^2-(4+(1-b_1)b_1)b_2)}{48-9b_1^2-(6-b_1^2)b_2^2}. \tag{20}$$

Thus, the profits of the firms are, respectively:

$$\pi_A^B = \frac{\alpha^2(3b_1^4(3-b_2)^2-2b_1^3(3-b_2)b_2^2-12b_1\left(48+b_2\left(8-16b_2+b_2^3\right)\right)+ 12(96-b_2(32+8b_2-b_2^3))+b_1^2(b_2(192-b_2(68+b_2(4-3b_2)))-72))}{2(48-9b_1^2-(6-b_1^2)b_2^2)^2},$$

$$\pi_R^B = \frac{\alpha^2(b_1(6+b_2-b_2^2)-3(8-b_2^2))^2}{2(48-9b_1^2-(6-b_1^2)b_2^2)^2},$$

$$\pi_F^B = \frac{3\alpha^2(3b_1^2+(4+b_1-b_1^2)b_2-16)^2}{2(48-9b_1^2-(6-b_1^2)b_2^2)^2}. \quad (21)$$

Note that the relationship between the HSR's profit and b_1 is U-shaped, while the HSR's profit is always decreasing in b_2, that is, $\frac{\partial \pi_R^B}{\partial b_1} \lessgtr 0$ when $b_1 \lessgtr A_{13}$ and $\frac{\partial \pi_R^B}{\partial b_2} < 0$. Additionally, the domestic and foreign airlines' profits are decreasing in b_i, that is, $\frac{\partial \pi_A^B}{\partial b_i} < 0$ and $\frac{\partial \pi_F^B}{\partial b_i} < 0$.

Finally, the social welfare is:

$$W^B = \frac{\alpha^2(2848+b_1^4(3-b_2)^2(5+2b_2)+2b_1^3(3-b_2)(15+b_2(7-b_2(2+b_2)))-2b_2(112+b_2(332-b_2(20+17b_2)))-4b_1(180+b_2(26-b_2(53+4(1-b_2)b_2)))+b_1^2(b_2(116+b_2(129-4b_2(5+b_2)))-654))}{2(48-9b_1^2-(6-b_1^2)b_2^2)^2}. \quad (22)$$

Note that social welfare is always decreasing in b_i, that is, $\frac{\partial W^B}{\partial b_i} < 0$.

Proposition 4: *Comparing the three firms' profits and social welfare in the three models, we have the following relationships:*

(i) $Min\{{\pi_R}^V, {\pi_R}^M\} > {\pi_R}^B$, $Min\{{\pi_A}^V, {\pi_A}^M\} > {\pi_A}^B$, and ${\pi_F}^B > Max\{{\pi_F}^M, {\pi_F}^V\}$;

(ii) $W^M > W^V > W^B$.

Proof: Comparing the three firms' profits and social welfares in the three models,[12] we have (i) ${\pi_R}^M > {\pi_R}^B$, ${\pi_R}^V > {\pi_R}^B$, ${\pi_A}^M > {\pi_A}^B$, ${\pi_A}^V > {\pi_A}^B$, but ${\pi_F}^M < {\pi_F}^B$, ${\pi_F}^V < {\pi_F}^B$; (ii) $W^M > W^V > W^B$.

Proposition 4 states that full privatization of the HSR with CSR activities always increases the domestic firms' profits, that is, ${\pi_R}^M > {\pi_R}^B$, ${\pi_R}^V > {\pi_R}^B$, ${\pi_A}^M > {\pi_A}^B$, and ${\pi_A}^V > {\pi_A}^B$, while it decreases the foreign firm' profit, that is, ${\pi_F}^M < {\pi_F}^B$ and ${\pi_F}^V < {\pi_F}^B$. That is, domestic and foreign firms have different preferences for the government regulations on the state-owned enterprise. The domestic firm will be better off if the privatization policy with CSR activities is implemented while the foreign airline will be worse off. Proposition 4 also states independent of the transport substitutability and types of CSR, full privatization with CSR activities always improves social welfare, that is, $W^M >$

[12] Numerical comparisons of the main results in the two models are provided in Figure 6 in Appendix B.

W^B and $W^V > W^B$. Full privatization with mandatory CSR yields the highest social welfare, while full nationalization yields the lowest social welfare. Thus, a full privatization policy with CSR activities always improves social welfare, which is independent of types of CSR activities. It also states that the privatization of HSR in an international transportation market requires an appropriate subsidy policy under the well-managed CSR regulations.

5. Conclusion

We consider an international transportation market in which an HSR firm competes with airline firms with differentiated services under government policies, and investigate a strategic relationship between CSR activities and transportation subsidy policy. We compare mandatory CSR and voluntary CSR as two scenarios, and show that the transport substitutability in the two legs is critical to the relationship between subsidy policy and CSR activities. In particular, when the transport substitutability between the HSR and the airline is low, mandatory CSR can be higher than voluntary CSR, and the optimal subsidy under mandatory CSR is higher than that under voluntary CSR. The opposite results are found when the transport substitutability between the HSR and airline is high. Finally, we investigate the impact of the privatization of the HSR firm on welfare and show that full privatization with CSR activities always improves social welfare under the appropriate subsidy policy, independent of the type of CSR activities and transport substitutability.

The findings of this paper are helpful to provide an important basis for the government to formulate supporting polices and promoting the reform of state-owned enterprises in the transportation industry. It can also enforce the legislated CSR in an era ex-post privatization where the CSR initiative of the HSR firm has become an important policy issue for society. We propose that rather than allowing the HSR firm to adopt voluntary CSR, there should be active legislation toward under-incentivizing of CSR or progressive guideline for discouraging over-incentivizing of CSR, by taking transport substitutability into policy consideration. Therefore, an ambitious regulatory framework of legal CSR with the appropriate subsidy policy is required for the HSR firm to promote social welfare in the international transportation market.

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Appendix A. The value of A_i

$A_1 = 9(s+\alpha)\big(7s+\alpha(6\beta-5)\big)+3\alpha\big(s+\alpha(3\beta-2)\big)b_2-(s+\alpha)\big(17s+\alpha(15\beta-13)\big)b_2^2+\alpha^2(1-\beta)b_2^3+(s+\alpha)(s-\alpha(1-\beta))b_2^4$,

$A_2 = 36(s^2(7\beta-5)+2s\alpha(7-3\beta+2\beta^2)+\alpha^2(19-13\beta+4\beta^2))+2\alpha(s(15+11\beta)+\alpha(51-37\beta+12\beta^2))b_2-(s^2(73\beta-51)+2s\alpha(75-32\beta+21\beta^2)+\alpha^2(201-137\beta+42\beta^2))b_2^2-\alpha(2s(3+\beta)+\alpha(15-10\beta+3\beta^2))b_2^3+(s^2(5\beta-3)+\alpha^2(15-10\beta+3\beta^2)+s\alpha(12-5\beta+3\beta^2))b_2^4$,

$A_3 = 6(\alpha^2(248\beta-50\beta^2-147)+6s\alpha(1+20\beta-4\beta^2)+3s^2(43-32\beta+6\beta^2))-2\alpha(1-\beta)(s(33-19\beta)-\alpha(93-23\beta))b_2+(s^2(88\beta-10\beta^2-149)+2s\alpha(20\beta^2-8-83\beta)+\alpha^2(167-298\beta+60\beta^2))b_2^2-2\alpha(1-\beta)(4\alpha(4-\beta)+s(1+\beta))b_2^3-2(-2s^2(2-\beta)+\alpha^2(2-5\beta+\beta^2)+s\alpha(\beta^2-2-3\beta))b_2^4$,

$A_4 = 4(5s-7\alpha)\alpha(3-\beta)^2+(\alpha^2(-711+426\beta-47\beta^2)-4s\alpha(81-66\beta+5\beta^2)+4s^2(81-30\beta+5\beta^2))b_2-(s-5\alpha)\alpha(-3+\beta)^2b_2^2+(s\alpha(18-15\beta+\beta^2)-s^2(18-6\beta+\beta^2)+\alpha^2(36-21\beta+2\beta^2))b_2^3$,

$A_5 = 9\alpha(8-b_2^2)^2-3\alpha b_1^2(72-17b_2^2+b_2^4)-b_1^3(9(7s+\alpha)+3\alpha b_2-(17s+2\alpha)b_2^2+sb_2^4)+b_1(36(7s+3\alpha)+22\alpha b_2-(73s+31\alpha)b_2^2-2\alpha b_2^3+(5s+2\alpha)b_2^4)$,

$A_6 = 80b_2^2-4b_2^4+b_1^2(117-20b_2^2+b_2^4)-432$,

$A_7 = 216-b_1^3(3-b_2)(3+2b_2)-2b_2^2(20-b_2^2)-b_1^2(90-17b_2^2+b_2^4)+b_1(72+b_2(17-b_2(19+(1-b_2)b_2)))$,

$A_8 = 2(12636+b_2^2(-20+b_2^2)(225-20b_2^2+b_2^4)-\sqrt{((108-20b_2^2+b_2^4)(117-20b_2^2+b_2^4)(7452+b_2(-1584+b_2(-2173+b_2(518+b_2(214+b_2(-56+b_2(-7+2b_2))))))))}$,

$A_9 = (117-20b_2^2+b_2^4)(72+b_2(11-b_2(17+(1-b_2)b_2)))$,

$A_{10} = 2b_1^3(3888+360b_2-1836b_2^2+70b_2^3+225b_2^4-19b_2^5-9b_2^6+b_2^7)-4b_1(20736+2736b_2-9648b_2^2-520b_2^3+1560b_2^4+37b_2^5-111b_2^6-b_2^7+3b_2^8)-b_1^2(40176-17856b_2-3304b_2^2+3344b_2^3-611b_2^4-204b_2^5+86b_2^6+4b_2^7-3b_2^8)$,

$A_{11} = (324(8-b_2^2)^2(86-18b_2^2+b_2^4)-54b_1(8-b_2^2)^2(60-17b_2^2+b_2^4)-6b_1^3(8-b_2^2)(1188-462b_2^2+55b_2^4-2b_2^6)+9b_1^2(8-b_2^2)(10080-3118b_2^2+329b_2^4-12b_2^6)+b_1^4(66744-26820b_2^2+4110b_2^4-289b_2^6+8b_2^8))$,

$A_{12} = (18b_1(8-b_2^2)^2(216+b_2(53+b_2(-54+b_2(-4+3b_2))))+27(8-b_2^2)^2(480+b_2(20+b_2(-108+b_2(-1+6b_2))))+b_1^5(-3+b_2)(3+b_2)(-1080+b_2(-222+b_2(360+b_2(35+b_2(-36+(-1+b_2)b_2)))))-3b_1^3(-8+b_2^2)(-2808+b_2(-894+b_2(900+b_2(148+b_2(-84+b_2(-5+2b_2)))))+3b_1^4(-8+b_2^2)(-2268+b_2(-171+b_2(738+b_2(29+b_2(-81+b_2(-1+3b_2)))))-3b_1^2(-8+b_2^2)(-20736+b_2(-1164+b_2(7200+b_2(224+b_2(-840+b_2(-10+33b_2))))))$,

$A_{13} = \frac{72+24b_2-9b_2^2+3b_2^3-\sqrt{3(1152+576b_2-248b_2^2-152b_2^3+5b_2^4+10b_2^5+b_2^6)}}{18+9b_2-2b_2^2-b_2^3}$.