Supplementary Materials

Proof of Proposition 1. According to the inverse induction method, the optimal decision of the EV manufacturer is first found by taking the partial derivatives of p_n, τ in the equation (1), respectively.

$$\frac{\partial \prod_m^R}{\partial p_n} = a + \tau Q - \beta\tau Q + c_1 - 2p_n$$

(S1)

$$\frac{\partial \prod_m^R}{\partial \tau} = ((1-\beta)\cdot p_n - c_1 + p_r + s)\cdot Q - 2b\tau$$

(S2)

When $4b - Q^2(1-\beta)^2 > 0$,the Hessian matrix $\begin{bmatrix} -2 & (1-\beta)\cdot Q \\ (1-\beta)\cdot Q & -2b \end{bmatrix}$ of equation (1) with respect to p_n and τ are negative definite and there exist a unique optimal solution. By setting equation (S1) and (S2) to zero. The reaction function of p_n and τ are obtained by the joint solution:

$$p_n = \frac{2b\cdot(a+c_1) + Q^2\cdot(1-\beta)\cdot(s - c_1 + p_r)}{4b - Q^2\cdot(1-\beta)^2}$$

(S3)

$$\tau = \frac{Q\cdot(a + 2s - a\cdot\beta - (1+\beta)c_1 + 2\cdot p_r)}{4b - Q^2\cdot(1-\beta)^2}$$

(S4)

Substituting the resulting p_n and τ into equation (2) and taking the partial derivative of p_r.

$$\frac{\partial \prod_r^R}{\partial p_r} = \frac{Q^2\cdot(2(f-c_2) - a\cdot(1-\beta) + (1+\beta)\cdot c_1 - 2s - 4\cdot p_r)}{4b - Q^2\cdot(1-\beta)^2}$$

(S5)

Since $\frac{\partial \prod_r^S}{\partial {p_r}^2} = -\frac{4Q^2}{4b - Q^2\cdot(1-\beta)^2} < 0$, $\prod_r^R$ is concave in p_r. By setting $\frac{\partial \prod_r^R}{\partial p_r}$ to zero, then p_r in the equilibrium state can be solved jointly.

$$p_r^R = \frac{2\cdot(f-c_2) + a\cdot(1-\beta) - (1+\beta)\cdot c_1 + 2(1+\beta)\cdot c_1 - 2a\cdot(1-\beta) - 2s}{4}$$

(S6)

Substituting the optimal p_r into equation (S3) and (S4), the optimal solution of p_n and τ are found as

$$p_n^R = \frac{1}{4} \cdot \left(2 \cdot (a + c_1) + Q^2 \cdot (1 - \beta) \cdot \frac{2(f - c_2) + a(1 - \beta) - (1 + \beta)c_1 + 2s}{4b - Q^2(1 - \beta)^2}\right)$$

(S7)

$$\tau^R = \frac{Q}{2} \cdot \frac{(2 \cdot (f - c_2) + a \cdot (1 - \beta) - (1 + \beta) \cdot c_1) + 2s}{4b - Q^2 \cdot (1 - \beta)^2}$$

(S8)

Let $\psi = 2(f - c_2) + a \cdot (1 - \beta) - (1 + \beta) \cdot c_1$, substituting ψ into equation (S6) -(S8), then equation (S6) - (S8) can be simplified as follows:

$$\begin{cases} p_n^R = \frac{1}{4} \cdot \left(2(a + c_1) + Q^2 \cdot (1 - \beta) \cdot \frac{\psi + 2s}{4b - Q^2(1 - \beta)^2}\right) \\ \tau^R = \frac{(\psi + 2s) \cdot Q}{2 \cdot (4b - Q^2(1 - \beta)^2)} \\ p_r^R = \frac{\psi + 2(1 + \beta) \cdot c_1 - 2a \cdot (1 - \beta) - 2s}{4} \end{cases}$$

Proof of Proposition 2. Find the partial derivatives of s in the equations (7)-(9), respectively, $\frac{\partial p_n^R}{\partial s} = \frac{Q^2 \cdot (1-\beta)}{2 \cdot (4b - Q^2 \cdot (1-\beta)^2)}$,$\frac{\partial \tau^R}{\partial s} = \frac{Q}{4b - Q^2 \cdot (1-\beta)^2}$, and $\frac{\partial p_r^R}{\partial s} = -\frac{1}{2} < 0$. Based on $4b - Q^2 \cdot (1 - \beta)^2 > 0$ and $\beta < 1$, we have $\frac{\partial p_n^R}{\partial s} > 0$,$\frac{\partial \tau^R}{\partial s} > 0$.

Proof of Proposition 3. The partial derivatives of β in the equations (8) and (9) respectively, are obtained as $\frac{\partial \tau^R}{\partial \beta} = -\frac{Q \cdot \left((8b - 2Q^2 \cdot (1-\beta)^2) \cdot (a + c_1) + 4Q^2 \cdot (1-\beta) \cdot (\psi + 2s)\right)}{(8b - 2Q^2 \cdot (1-\beta)^2)^2}$,$\frac{\partial p_r^R}{\partial \beta} = \frac{a + c_1}{4}$. It is easy to know$\frac{\partial p_r^R}{\partial \beta} > 0$. From equation (8), we have $\tau^R = \frac{(\psi + 2s) \cdot Q}{2 \cdot (4b - Q^2 \cdot (1-\beta)^2)} > 0$, then $\psi + 2s > 0$; based on $4b - Q^2 \cdot (1 - \beta)^2 > 0, \beta < 1, k > 0$, we have $\frac{\partial \tau^R}{\partial \beta} < 0$.The partial derivatives of β in the equation (7) (10) and (11), are obtained as

$$\begin{cases} \frac{\partial p_n^R}{\partial \beta} = -\frac{Q^2(4b(a(1 - \beta) + f - \beta c_1 - c_2 + s) + Q^2(1 - \beta)^2(f - c_1 - c_2 + s))}{2(4b - Q^2(1 - \beta)^2)^2} \\ \frac{\partial \prod_m^{R^*}}{\partial \beta} = -\frac{Q^2 \cdot (\psi + 2s) \cdot (2b \cdot (a + c_1) + Q^2 \cdot (1 - \beta) \cdot (f + s - c_1 - c_2))}{4 \cdot (4b - Q^2 \cdot (1 - \beta)^2)^2} \\ \frac{\partial \prod_r^{R^*}}{\partial \beta} = -\frac{Q^2 \cdot (\psi + 2s) \cdot (2b \cdot (a + c_1) + Q^2 \cdot (1 - \beta) \cdot (f + s - c_1 - c_2))}{2 \cdot (4b - Q^2 \cdot (1 - \beta)^2)^2} \end{cases}$$

Where $\psi = 2(f - c_2) + a \cdot (1 - \beta) - (1 + \beta) \cdot c_1$. By setting $\frac{\partial p_n^R}{\partial \beta}$, $\frac{\partial \prod_m^{R^*}}{\partial \beta}$ and $\frac{\partial \prod_r^{R^*}}{\partial \beta}$to zero, from equation (8), we have $\tau^R = \frac{(\psi + 2s) \cdot Q}{2 \cdot (4b - Q^2 \cdot (1-\beta)^2)} > 0$, then $\psi + 2s > 0$. Based on $4b - Q^2 \cdot (1 - \beta)^2 > 0, \beta < 1$, and $k > 0$, when $\beta \in [0, \min(1, \Gamma_1, \Gamma_2)]$, we have $\frac{\partial p_n^R}{\partial \beta} < 0$, $\frac{\partial \prod_m^{R^*}}{\partial \beta} < 0$, and $\frac{\partial \prod_r^{R^*}}{\partial \beta} < 0$, where $\Gamma_1 = 1 + 2 \cdot \frac{f + s - c_1 - c_2}{a + c_1}$ and $\Gamma_2 = \frac{1}{Q^2(f + s - c_1 - c_2)}\left(2b(a + c_1) + Q^2(f + s - c_1 - c_2) + 2\sqrt{b^2(a + c_1)^2 - bQ^2(f + s - c_1 - c_2)^2}\right) = 1 + 2 \cdot \frac{b \cdot (a + c_1) + \sqrt{b^2 \cdot (a + c_1)^2 - bQ^2 \cdot (f + s - c_1 - c_2)^2}}{Q^2 \cdot (f + s - c_1 - c_2)}$.

Proof of Proposition 4. According to the inverse induction method, the optimal decision of the EV manufacturer is first found by taking the partial derivatives of p_n , τ in equation (4), respectively.

$$\frac{\partial \prod_m^D}{\partial p_n} = a + t + Q \cdot (1-\beta)\tau + c_1 - 2p_n \tag{S9}$$

$$\frac{\partial \prod_m^D}{\partial \tau} = -2b\tau + Q \cdot (kt - c_1 + (1-\beta)p_n + p_r) \tag{S10}$$

When $4b - Q^2(1-\beta)^2 > 0$,the Hessian matrix $\begin{bmatrix} -2 & (1-\beta)\cdot Q \\ (1-\beta)\cdot Q & -2b \end{bmatrix}$ of equation (4) with respect to p_n and τ are negative definite and there exist a unique optimal solution. By setting equation (S9) and (S10) to zero. The reaction function of p_n and τ are obtained by the joint solution:

$$p_n = -\frac{-2b(a+t+c_1)+Q^2(-1+\beta)(kt-c_1+p_r)}{4b-Q^2(-1+\beta)^2} \tag{S11}$$

$$\tau = \frac{Q(a+t+2kt-a\beta-t\beta-(1+\beta)c_1+2p_r)}{4b-Q^2(-1+\beta)^2} \tag{S12}$$

Substituting the resulting p_n and τ into equation (5) and taking the partial derivative of p_r.

$$\frac{\partial \pi_r^D}{\partial p_r} = \frac{Q^2(a-2f+t+2kt-a\beta-t\beta-(1+\beta)c_1+2c_2+4p_r)}{-4b+Q^2(1-\beta)^2} \tag{S13}$$

Since $\frac{\partial \prod_r^D}{\partial {p_r}^2} = -\frac{4Q^2}{4b-Q^2\cdot(1-\beta)^2} < 0$, $\prod_r^D$ is concave in p_r. By setting $\frac{\partial \prod_r^D}{\partial p_r}$ to zero, then p_r in the equilibrium state can be solved jointly.

$$p_r^D = \frac{2(f-c_2)-a\cdot(1-\beta)+(1+\beta)\cdot c_1-(1-\beta+2k)\cdot t}{4} \tag{S14}$$

Substituting the optimal p_r into equation (S11) and (S12), the optimal solution of p_n and τ are found as

$$p_n^D = \frac{1}{4}\cdot\left(2\cdot(a+c_1+t)+Q^2\cdot(1-\beta)\cdot\frac{2(f-c_2)+a\cdot(1-\beta)-(1+\beta)\cdot c_1+(1-\beta+2k)\cdot t}{4b-Q^2(1-\beta)^2}\right) \tag{S15}$$

$$\tau^D = \frac{Q}{2} \cdot \frac{2(f-c_2) + a\cdot(1-\beta) - (1+\beta)\cdot c_1 + (1-\beta+2k)\cdot t}{4b - Q^2(1-\beta)^2}$$

(S16)

Let $\psi = 2(f-c_2) + a\cdot(1-\beta) - (1+\beta)\cdot c_1$, substituting ψ into equation (S14) -(S16), then equation (S14) - (S16) can be simplified as follows:

$$\begin{cases} p_n^D = \frac{1}{4}\cdot\left(2\cdot(a+c_1+t) + Q^2\cdot(1-\beta)\cdot\frac{\psi+(1-\beta+2k)\cdot t}{4b-Q^2(1-\beta)^2}\right) \\ \tau^D = \frac{Q}{2}\cdot\frac{\psi+(1-\beta+2k)\cdot t}{4b-Q^2(1-\beta)^2} \\ p_r^D = \frac{\psi+2(1+\beta)c_1-2a\cdot(1-\beta)-(1-\beta+2k)\cdot t}{4} \end{cases}$$

Proof of Proposition 5. Find the partial derivatives of t in the equations (13)-(15), respectively, $\frac{\partial p_n^D}{\partial t} = \frac{8b-Q^2\cdot(1-\beta)\cdot(1-\beta-2k)}{4\cdot(4b-Q^2\cdot(1-\beta)^2)}$, $\frac{\partial\tau^D}{\partial t} = \frac{Q\cdot(1-\beta+2k)}{2\cdot(4b-Q^2\cdot(1-\beta)^2)}$, $\frac{\partial p_r^D}{\partial t} = -\frac{1-\beta+2k}{4}$. Based on $4b - Q^2\cdot(1-\beta)^2 > 0$, $\beta < 1$, and $k > 0$, we have $\frac{\partial p_n^D}{\partial t} > 0$, $\frac{\partial\tau^D}{\partial t} > 0$, $\frac{\partial p_r^D}{\partial t} < 0$.

Proof of Proposition 6. The partial derivatives of β in the equation (13) (16) and (17) respectively, are obtained as

$$\begin{cases} \frac{\partial p_n^D}{\partial\beta} = -\frac{Q^2\cdot(4b\cdot(a(1-\beta)+f+t+k\cdot t-\beta\cdot t-\beta\cdot c_1-c_2)+Q^2(1-\beta)^2(f+k\cdot t-c_1-c_2))}{2\cdot(4b-Q^2\cdot(1-\beta)^2)^2} \\ \frac{\partial\prod_m^{D^*}}{\partial\beta} = -\frac{Q^2\cdot(\psi+(1-\beta+2k))\cdot(2b\cdot(a+c_1+t)+Q^2\cdot(1-\beta)\cdot(f+k\cdot t-c_1-c_2))}{4\cdot(4b-Q^2\cdot(1-\beta)^2)^2} \\ \frac{\partial\prod_r^{D^*}}{\partial\beta} = -\frac{Q^2\cdot(\psi+(1-\beta+2k))\cdot(2b\cdot(a+c_1+t)+Q^2\cdot(1-\beta)\cdot(f+k\cdot t-c_1-c_2))}{4\cdot(4b-Q^2\cdot(1-\beta)^2)^2} \end{cases}$$

where $\psi = 2(f-c_2) + a\cdot(1-\beta) - (1+\beta)\cdot c_1$. By setting $\frac{\partial p_n^D}{\partial\beta}$, $\frac{\partial\prod_m^{D^*}}{\partial\beta}$ and $\frac{\partial\prod_r^{D^*}}{\partial\beta}$ to zero, from equation (14), we have $\tau^D = \frac{Q}{2}\cdot\frac{\psi+(1-\beta+2k)\cdot t}{4b-Q^2(1-\beta)^2} > 0$, then $\psi + (1-\beta+2k)\cdot t > 0$. Based on $4b - Q^2\cdot(1-\beta)^2 > 0$, $\beta < 1$, and $k > 0$, when $\beta \in [0, \min(\Gamma_3, \Gamma_4)]$, we have $\frac{\partial p_n^D}{\partial\beta} < 0$, $\frac{\partial\prod_m^{D^*}}{\partial\beta} < 0$, and $\frac{\partial\prod_r^{D^*}}{\partial\beta} < 0$, where $\Gamma_3 = 1 + 2\cdot\frac{f+k\cdot t-c_1-c_2}{a+t+c_1}$ and $\Gamma_4 = \frac{2b\cdot(a+c_1+t)+Q^2(f+k\cdot t-c_1-c_2)+2\sqrt{b^2(a+c_1+t)^2-bQ^2(f+k\cdot t-c_1-c_2)^2}}{Q^2(f+k\cdot t-c_1-c_2)} = 1 + 2\cdot \frac{b\cdot(a+c_1+t)+\sqrt{b^2\cdot(a+c_1+t)^2-bQ^2\cdot(f+k\cdot t-c_1-c_2)^2}}{Q^2\cdot(f+k\cdot t-c_1-c_2)}$.

Proof of Proposition 7. From $q^R - q^D = \frac{8bt+Q^2(2s(1+\beta)-t(3-4\beta+\beta^2+2k(1+\beta)))}{16b-4Q^2(1-\beta)^2}$, based on $4b - Q^2\cdot(1-\beta)^2 > 0$, $\beta < 1$, and $k > 0$, when $0 < s < \chi_1\cdot t$, we have $q^R < q^D$; when $s = \chi_1\cdot t$, we have $q^R = q^D$; when $s > \chi_1\cdot t$, we have $q^R > q^D$, where $\chi_1 = k + \frac{Q^2\cdot(3-4\beta+\beta^2)-8b}{2Q^2(1+\beta)}$

Proof of Proposition 8. From $\tau^R - \tau^D = \frac{Q\cdot(2s-(1-\beta+2k)\cdot t)}{2\cdot(4b-Q^2(1-\beta)^2)}$, $p_r^R - p_r^D = \frac{(1-\beta+2k)\cdot t-2s}{4}$, $\prod_r^{R^*} - \prod_r^{D^*} = \frac{Q^2\cdot(2s-(1-\beta+2k)\cdot t)(2s+(1-\beta+2k)\cdot t+2\psi)}{8\cdot(4b-Q^2(1-\beta)^2)}$, based on $4b - Q^2\cdot(1-\beta)^2 > 0$, $\beta < 1$, and $k > 0$, when $0 < s < \chi_2 \cdot t$, we have $\tau^R < \tau^D$; $p_r^R > p_r^D$; when $s = \chi_2 \cdot t$, we have $\tau^R = \tau^D$; $p_r^R = p_r^D$; when $s > \chi_2 \cdot t$, we have $\tau^R > \tau^D$; $p_r^R < p_r^D$. It follows from equation (14) that $\tau^D = \frac{Q}{2} \cdot \frac{\psi+(1-\beta+2k)\cdot t}{4b-Q^2(1-\beta)^2} > 0$, then $\psi + (1-\beta+2k)\cdot t > 0$. Thus, we have $2s + (1-\beta+2k)\cdot t + 2\psi > 0$. Therefore, when $0 < s < \chi_2 \cdot t$, we have $\prod_r^{R^*} < \prod_r^{D^*}$; when $s = \chi_2 \cdot t$, we have $\prod_r^{R^*} = \prod_r^{D^*}$; when $s > \chi_2 \cdot t$, we have $\prod_r^{R^*} > \prod_r^{D^*}$, where $\chi_2 = k + \frac{1-\beta}{2}$.

Proof of Proposition 9. When $s = t$, we have $\tau^R - \tau^D = \frac{Q\cdot(2s-(1-\beta+2k)\cdot t)}{2\cdot(4b-Q^2(1-\beta)^2)}$. Based on $4b - Q^2 \cdot (1-\beta)^2 > 0$, $\beta < 1$, and $k > 0$, when $k > \frac{1+\beta}{2}$,we have $\tau^R > \tau^D$; when $k = \frac{1+\beta}{2}$, we have $\tau^R = \tau^D$; when $0 < k < \frac{1+\beta}{2}$, we have $\tau^R < \tau^D$.

Proof of Proposition 10. ${\prod_{gov}^R}^* - {\prod_{gov}^D}^* = \frac{t^2\cdot(16b+Q^2\cdot(4k\cdot(1-\beta+k)-3\cdot(1-\beta)^2))-2Q^2\cdot(4e_b+4e_p+\psi)\cdot(1-\beta+2k)\cdot t+4Q^2\cdot s\cdot(4e_b+4e_p+\psi-s)}{16\cdot(4b-Q^2\cdot(-1+\beta)^2)}$. To simplify the equation, let $A = 4e_p + 4e_b + \psi$ and $L = 16b + Q^2 \cdot (4k\cdot(1-\beta+k) - 3\cdot(1-\beta)^2)$, based on $4b - Q^2\cdot(1-\beta)^2 > 0$, we have $16b - 3Q^2\cdot(1-\beta)^2 > 0$, then we have $L > 0$; and ${\prod_{gov}^R}^* - {\prod_{gov}^D}^* = \frac{Lt^2-2Q^2\cdot A\cdot(1-\beta+2k)\cdot t+4Q^2\cdot s\cdot(A-s))}{16(4b-Q^2\cdot(-1+\beta)^2)}$. According to ${\prod_{gov}^R}^* - {\prod_{gov}^D}^* = \frac{Lt^2-2Q^2\cdot A\cdot(1-\beta+2k)\cdot t+4Q^2\cdot s(A-s))}{16\cdot(4b-Q^2(1-\beta)^2)}$, t_1 and t_2 can be solved as follows:

$$\begin{cases} t_1 = \dfrac{Q^2\cdot A\cdot(1+2k-\beta) - \sqrt{Q^4\cdot A\cdot(1+2k-\beta)^2 - 4\cdot L^2\cdot Q^2\cdot s\cdot(A-s)}}{L^2} \\ t_2 = \dfrac{Q^2\cdot A\cdot(1+2k-\beta) + \sqrt{Q^4\cdot A\cdot(1+2k-\beta)^2 - 4\cdot L^2\cdot Q^2\cdot s\cdot(A-s)}}{L^2} \end{cases}$$

Therefore, when $0 < t < t_1$ or $t > t_2$, we have ${\prod_{gov}^R}^* > {\prod_{gov}^D}^*$; when $t_1 < t < t_2$, we have ${\prod_{gov}^R}^* < {\prod_{gov}^D}^*$.