Cross-ownership and strategic environmental corporate social responsibility under price competition

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Online Appendix

We examine a unilateral cross-shareholding case where only firm 1 holds k ($0<k<0.5$) shares of firm 2, while the reverse is not true. The objective functions of owners are given by: $\Pi_0=\pi_0$, $\Pi_1=\pi_1+k\pi_2$ and $\Pi_2=(1-k)\pi_2$. Other assumptions are the same as the basic model.

From the first-order conditions of stage 1, we obtain the following firm reaction functions:

$$h_0=R(h_1,h_2)=\frac{1}{A_{0u}}r^2(r+1)(rk+6r+4)[r(r+1)(3r+2)(1-k)h_1+r(r+1)(rk+3r+2)h_2+(1-r)(3r+2)^2(1-k)w] \quad \text{(A1)}$$

$$h_1=R(h_0,h_2)=\frac{r(r+1)}{(3r+2)(1-k)A_{1u}}\begin{pmatrix}(r+1)\{r^2(1-k)(5rk+2k+6r+4)h_0+[(3r^3+2r^2)k^2+(7r^3-6r^2-20r\\-8)k+4r^2+6r^3]h_2\}+r(1-r)(3r+2)(1-k)(5rk+2k+6r+4)w\end{pmatrix} \quad \text{(A2)}$$

$$h_2=R(h_0,h_1)=\frac{1}{A_{1u}}r^2(r+1)(1-k)(k+2)[r(r+1)h_0+r(r+1)h_1+(1-r)(3r+2)w] \quad \text{(A3)}$$

where $A_{0u}=(1-k)[-r^4(2r+1)(9r^3+r^2-12r-6)k^2+2r^2(3r+2)(35r^4+20r^3-47r^2-48r-12)k-(3r+2)^2(2r^5+74r^4+42r^3-94r^2-96r-24)]$

and $A_{1u}=r^4(2r+1)(1-r)k^2+2r^2(11r^3-r^2-13r-5)k-2r^5-74r^4-42r^3+94r^2+96r+24$.

In the comparative analysis, we find the following Lemma.

Lemma 1′. (i) h_0 increases with h_1 and h_2; (ii) h_1 increases with h_0, and h_1 increases (decreases) with h_2 if k is small (large); (iii) h_2 increases with h_0 and h_1.

Proof. We set $M_u=r(r+1)^2[(3r^3+2r^2)k^2+(7r^3-6r^2-20r-8)k+4r^2+6r^3]$ and can prove $M_u>(<)0$ if $k<(>)k_u(r)$ (where $k_u(r)=\dfrac{-7r^3+6r^2+20r+8-\sqrt{-23r^6-180r^5-276r^4+128r^3+496r^2+320r+64}}{2r^2(3r+2)}\in(0,0.5)$). In addition, $A_{0u}>0$ and $A_{1u}>0$. Thus, we have: (i) $\dfrac{\partial h_0}{\partial h_1}=\dfrac{\partial R(h_1,h_2)}{\partial h_1}=\dfrac{r^3(r+1)^2(rk+6r+4)(3r+2)(1-k)}{A_{0u}}>0$ and $\dfrac{\partial h_0}{\partial h_2}=\dfrac{\partial R(h_1,h_2)}{\partial h_2}=\dfrac{r^3(r+1)^2(rk+6r+4)(rk+3r+2)}{A_{0u}}>0$; (ii) $\dfrac{\partial h_1}{\partial h_0}=\dfrac{\partial R(h_0,h_2)}{\partial h_0}=\dfrac{r^3(r+1)^2(1-k)(5rk+2k+6r+4)}{(3r+2)(1-k)A_{1u}}>0$, and $\dfrac{\partial h_1}{\partial h_2}=\dfrac{\partial R(h_0,h_2)}{\partial h_2}=\dfrac{M_u}{(3r+2)(1-k)A_{1u}}>(<)0$ if $k<(>)k_u(r)$; (iii) $\dfrac{\partial h_2}{\partial h_0}=\dfrac{\partial R(h_0,h_1)}{\partial h_0}=\dfrac{r^3(r+1)^2(1-k)(k+2)}{A_{1u}}>0$

and $\frac{\partial h_2}{\partial h_1} = \frac{\partial R(h_0, h_1)}{\partial h_1} = \frac{r^3(r+1)^2(1-k)(k+2)}{A_{1u}} > 0$.

Lemma 1′ represents that the choices of ECSR under unilateral cross-ownership are strategic complements in most cases. However, if k is sufficiently large, h_1 decreases with h_2 (i.e., their relationship is as strategic substitutes).

Similar to the basic model, we obtain the following optimal ECSR levels:

$$h_0^U = \frac{r^2(1-r^2)(kr+4+6r)\Phi_u w}{\vartheta_u} \tag{A4}$$

$$h_1^U = \frac{r^2(1-r^2)\psi_u w}{\vartheta_u} \tag{A5}$$

$$h_2^U = \frac{r^2(k+2)(1-k)(1-r^2)\rho_u w}{\vartheta_u} \tag{A6}$$

Note that Φ_u, ψ_u, ρ_u and ϑ_u are given in appendix C. Using (A4)~(A6), we obtain equilibrium prices, abatement levels and outputs: $p_i^U = p_i(h_0^U, h_1^U, h_2^U)$, $y_i^U = y_i(h_i^U)$ and $q_i^U = q_i(h_0^U, h_1^U, h_2^U)$ ($i = 0, 1, 2$). Then, we can obtain the environmental damage and social welfare in equilibrium: $D^U = D(h_0^U, h_1^U, h_2^U)$ and $SW^U = SW(h_0^U, h_1^U, h_2^U)$.[1] Using (A4)~(A6), we can prove Propositions 1′ and 2′.

Proposition 1′. (i) $h_i^U > 0$ ($i = 0, 1, 2$); (ii) $h_2^U < h_0^U < h_1^U$; (iii) $h_1^U - h_0^U < h_0^U - h_2^U$.

Proof: (i) Because $\vartheta_u > 0$, $r^2(1-r^2)(kr+4+6r)\Phi_u > 0$, $r^2(1-r^2)\psi_u > 0$ and $r^2(k+2)(1-k)(1-r^2)\rho_u > 0$ for $0 < k < 0.5$ and $0 < r < 1$, $h_0^U > 0$, $h_1^U > 0$ and $h_2^U > 0$; (ii) Because

[1] Note that to ensure $SW^u \geq 0$, d cannot be too high and satisfies $0 < d \leq \frac{G_u}{Z_u^2}$ (G_u and Z_u are given in appendix C).

$h_0^U - h_2^U = \frac{r^2(1-r^2)[(kr+4+6r)\Phi_u - (k+2)(1-k)\rho_u]w}{\vartheta_u} > 0$ and $h_1^U - h_0^U = \frac{r^2(1-r^2)[\psi_u - (kr+4+6r)\Phi_u]w}{\vartheta_u} > 0$; (iii) Because $(h_1^U - h_0^U) - (h_0^U - h_2^U) = \frac{r^2(1-r^2)[\psi_u + (k+2)(1-k)\rho_u - 2(kr+4+6r)\Phi_u]w}{\vartheta_u} < 0$, $h_1^U - h_0^U < h_0^U - h_2^U$.

Proposition 2′. (i) $\frac{\partial h_0^U}{\partial k} > 0$; (ii) $\frac{\partial h_1^U}{\partial k} > 0$; (iii) $\frac{\partial h_2^U}{\partial k} < 0$.

Proof: (i) $\frac{\partial h_0^U}{\partial k} = \frac{r^2(1-r^2)[r\Phi_u\vartheta_u + (kr+4+6r)(\Phi_u{}'\vartheta_u - \Phi_u\vartheta_u{}')]w}{\vartheta_u^2} > 0$; (ii) $\frac{\partial h_1^U}{\partial k} = \frac{r^2(1-r^2)(\psi_u{}'\vartheta_u - \psi_u\vartheta_u{}')w}{\vartheta_u^2} > 0$; (iii) $\frac{\partial h_2^U}{\partial k} = \frac{r^2(1-r^2)[-(2k+1)\rho_u\vartheta_u + (k+2)(1-k)(\rho_u{}'\vartheta_u - \rho_u\vartheta_u{}')]w}{\vartheta_u^2} < 0$.

Using the equilibrium prices, outputs, abatement levels, environmental damage and social welfare, we can prove Lemma 2′ and Proposition 3′.

Lemma 2′. (i) $\frac{\partial p_i^U}{\partial k} > 0$ ($i = 0,1,2$); (ii) $\frac{\partial Q^U}{\partial k} < 0$ where $Q^U = \sum_{i=0}^{2} q_i^U$; (iii) $\frac{\partial y_i^U}{\partial k} > 0$ ($i = 0,1,2$); (iv) $\frac{\partial (E^U)}{\partial k} < 0$ where $E^U = \sum_{i=0}^{2} e_i^U$.

Proof: We can obtain $p_i^U = \frac{(1-r)\beta_{iu}w}{\vartheta_u}$, $Q^U = \frac{\lambda_u w}{(2r+1)\vartheta_u}$, $y_i^U = \frac{r^2(1-r^2)\alpha_{iu}w}{\vartheta_u}$ and $E^U = \frac{\varsigma_u w}{(2r+1)\vartheta_u}$, where β_{iu}, α_{iu}, λ_u and ς_u ($i = 0,1,2$) are given in appendix C. Then, we can prove: (i) $\frac{\partial p_i^U}{\partial k} = \frac{(1-r)(\beta_{iu}{}'\vartheta_u - \beta_{iu}\vartheta_u{}')w}{\vartheta_u^2} > 0$; (ii) $\frac{\partial Q^U}{\partial k} = \frac{(\lambda_u{}'\vartheta_u - \lambda_u\vartheta_u{}')w}{(2r+1)\vartheta_u^2} < 0$; (iii) $\frac{\partial y_i^U}{\partial k} = \frac{r^2(1-r^2)(\alpha_{iu}{}'\vartheta_u - \alpha_{iu}\vartheta_u{}')w}{\vartheta_u^2} > 0$; (iv) $\frac{\partial (E^U)}{\partial k} = \frac{(\varsigma_u{}'\vartheta_u - \varsigma_u\vartheta_u{}')w}{(2r+1)\vartheta_u^2} < 0$.

Proposition 3′. (i) $\frac{\partial D^U}{\partial k} < 0$; (ii) There exists $\hat{d}(r,k)$ ($\hat{d}(r,k) > 0$) making $\frac{\partial SW^U}{\partial k} < (>) 0$ if $d < (>) \hat{d}(r,k)$.

Proof: (i) We can obtain $D^U = \frac{Z_u^2 dw^2}{2(2r+1)^2\vartheta_u^2}$ where Z_u is given in appendix C. Then, we obtain $\frac{\partial D^U}{\partial k} = \frac{Z_u(Z_u{}'\vartheta_u - Z_u\vartheta_u{}')dw^2}{(2r+1)^2\vartheta_u^3} < 0$; (ii) We obtain $SW^U = \frac{(G_u - Z_u^2 d)w^2}{2(2r+1)^2\vartheta_u^2}$ where G_u is given in appendix C. Then, we obtain $\frac{\partial SW^U}{\partial k} = \frac{[2(Z_u^2\vartheta_u{}' - Z_u Z_u{}'\vartheta_u)d - (2G_u\vartheta_u{}' - G_u{}'\vartheta_u)]w^2}{8(2r+1)^2\vartheta_u^3}$. We can prove that $\vartheta_u > 0$,

$Z_u{}^2\vartheta_u' - Z_u Z_u'\vartheta_u > 0$ and $2G_u\vartheta_u' - G_u'\vartheta_u > 0$. We set $\hat{d}(r,k) = \dfrac{2G_u\vartheta_u' - G_u'\vartheta_u}{2(Z_u{}^2\vartheta_u' - Z_u Z_u'\vartheta_u)}$ and thus obtain $\dfrac{\partial SW^B}{\partial k} < (>) 0$ if $d < (>) \hat{d}(r,k)$.

Proposition 3′ (i) implies that cross ownership can decrease environmental damage and improve environmental quality, similar to Proposition 3(i) under bilateral cross-shareholding. As a result, Proposition 3′ (ii) implies that cross ownership decreases social welfare when environmental damage is minimal; however, it increases social welfare when environmental damage is severe, similar to the bilateral cross-shareholding case.

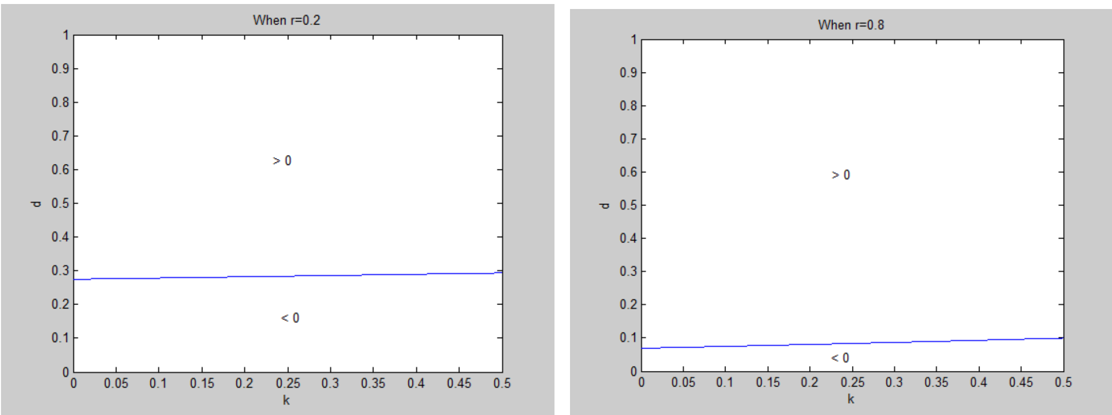

Figure A1. The sign of $\dfrac{\partial SW^U}{\partial k}$ under unilateral cross ownership.

Appendix C

$$\Phi_u = [r^2(r-1)(2+3r)(2r+1)k - 35r^4 - 20r^3 + 47r^2 + 48r + 12][r^2(6r^3 - 7r - 3)k - 35r^4 - 20r^3 + 47r^2 + 48r + 12],$$

$$\psi_u = \begin{pmatrix} [r^2(2r+1)(9r^3 + r^2 - 12r - 6)k - (2+3r)(35r^4 + 20r^3 - 47r^2 - 48r - 12)][r(10r^4 - 4r^3 - 15r^2 \\ -9r - 2)k^2 + (12r^5 - 61r^4 - 42r^3 + 59r^2 + 56r + 12)k - 70r^4 - 40r^3 + 94r^2 + 96r + 24] \end{pmatrix},$$

$$\rho_u = [r^2(r-1)(2+3r)(2r+1)k + 12 - 35r^4 - 20r^3 + 47r^2 + 48r][r^2(2r+1)(9r^3 + r^2 - 12r - 6)k - (2+3r)(35r^4 + 20r^3 - 47r^2 - 48r - 12)],$$

$$\vartheta_u = \begin{pmatrix} -r^8(9r^3+r^2-12r-6)(1-r)^2(2r+1)^3k^4+2r^6(2r+1)(390r^8-210r^7-1201r^6+116r^5+1419r^4+430r^3- \\ 555r^2-384r-69)k^3-r^4(216r^{11}+13802r^{10}+5271r^9-52381r^8-44668r^7+56358r^6+86007r^5+9775r^4- \\ 43066r^3-31930r^2-9360r-1032)k^2+2r^2(-12-48r-47r^2+20r^3+35r^4)(36r^8+842r^7+327r^6-2184r^5 \\ -1950r^4+950r^3+1895r^2+864r+132)k-2(2+3r)(r^4+13r^3-r^2-15r-6)(35r^4+20r^3-47r^2-48r-12)^2 \end{pmatrix},$$

$$\beta_{0u} = \begin{pmatrix} [(6r^5-7r^3-3r^2)k+12+48r+49r^2-16r^3-33r^4][(6r^5+r^4-5r^3-2r^2)k-35r^4 \\ -20r^3+47r^2+48r+12][(6r^5-7r^3-3r^2)k-35r^4-20r^3+47r^2+48r+12] \end{pmatrix},$$

$$\beta_{1u} = \begin{pmatrix} [(-24r^3+18r^6-6r^2-23r^4+11r^5)k+24-105r^5+132r+101r^3+238r^2-130r^4][r^5(2r+1)^2(r \\ -1)^2k^3+r^3(-44r+12r^6-9r^2-48r^5+74r^3+12r^4-13)k^2-r(-127r^2-244r^5+224r^3-156r \\ -115r^6+136r^7-36+206r^4)k+(11r^3-2r^2-15r-6)(35r^4+20r^3-47r^2-48r-12)] \end{pmatrix},$$

$$\beta_{2u} = \begin{pmatrix} [(-r^2-r^3+2r^4)k+15r+2r^2-11r^3+6][(6r^5+r^4-5r^3-2r^2)k-35r^4-20r^3+47r^2+48r \\ +12][(-24r^3+18r^6-6r^2-23r^4+11r^5)k+24-105r^5+132r+101r^3+238r^2-130r^4] \end{pmatrix},$$

$$\alpha_{0u} = (kr+4+6r)[(6r^5-7r^3-3r^2)k-35r^4-20r^3+47r^2+48r+12][(6r^5+r^4-5r^3-2r^2)k-35r^4-20r^3+47r^2+48r+12] \ ,$$

$$\alpha_{1u} = \begin{pmatrix} [(-24r^3+18r^6-6r^2-23r^4+11r^5)k+24-105r^5+132r+101r^3+238r^2-130r^4][(-9r^2-2r+ \\ 10r^5-4r^4-15r^3)k^2+(56r+12-42r^3-61r^4+59r^2+12r^5)k+96r-70r^4+24-40r^3+94r^2] \end{pmatrix},$$

$$\alpha_{2u} = \begin{pmatrix} (k+2)[(6r^5+r^4-5r^3-2r^2)k-35r^4-20r^3+47r^2+48r+12][(-24r^3+ \\ 18r^6-6r^2-23r^4+11r^5)k+24-105r^5+132r+101r^3+238r^2-130r^4] \end{pmatrix},$$

$$\lambda_u = \begin{pmatrix} -r^7(-6-12r+r^2+9r^3)(r-1)^2(2r+1)^4k^4+r^5(162r^9+582r^8-903r^7-1970r^6+902r^5+2548r^4 \\ +381r^3-1098r^2-630r-102)(2r+1)^2k^3-r^3(2r+1)(5886r^{11}+12737r^{10}-18838r^9-57181r^8 \\ -5126r^7+78079r^6+60306r^5-15375r^4-42140r^3-23188r^2-5640r-528)k^2+r(2034r^9+ \\ 3960r^8-3191r^7-12032r^6-6058r^5+6434r^4+9019r^3+4310r^2+924r+72)(35r^4+20r^3- \\ 47r^2-48r-12)k-(9r+6)(r+1)(13r^3-15r-6)(35r^4+20r^3-47r^2-48r-12)^2 \end{pmatrix},$$

$$\varsigma_u = \begin{pmatrix} -r^7(-6-12r+r^2+9r^3)(r-1)^2(2r+1)^4k^4+r^5(324r^9+565r^8-1473r^7-2134r^6+1556r^5+2985r^4+ \\ 225r^3-1342r^2-720r-114)(2r+1)^2k^3+r^3(2r+1)(648r^{12}-9234r^{11}-18715r^{10}+29376r^9+77615r^8 \\ +506r^7-103597r^6-72428r^5+22121r^4+51020r^3+26808r^2+6312r+576)k^2-r(35r^4+20r^3- \\ 47r^2-48r-12)(432r^{10}-2160r^9-5731r^8+2803r^7+14446r^6+7676r^5-7121r^4-10075r^3-4698r^2 \\ -972r-72)k+(9r+6)(r+1)(r^2-3r-2)(4r^2-3r-3)(35r^4+20r^3-47r^2-48r-12)^2 \end{pmatrix},$$

$$Z_u = \begin{pmatrix} -r^7(9r^3+r^2-12r-6)(1-r)^2(2r+1)^4k^4+r^5(2r+1)^2(324r^9+565r^8-1473r^7-2134r^6+1556r^5+2985r^4+225r^3-1342r^2 \\ -720r-114)k^3+r^3(2r+1)(648r^{12}-9234r^{11}-18715r^{10}+29376r^9+77615r^8+506r^7-103597r^6-72428r^5+22121r^4+ \\ 51020r^3+26808r^2+6312r+576)k^2-r(35r^4+20r^3-47r^2-48r-12)(432r^{10}-2160r^9-5731r^8+2803r^7+14446r^6+ \\ 7676r^5-7121r^4-10075r^3-4698r^2-972r-72)k+3(3r+2)(r+1)(4r^2-3r-3)(r^2-3r-2)(35r^4+20r^3-47r^2-48r-12)^2 \end{pmatrix} \quad \text{and}$$

$$G_u = \left(2r+1\right)\left(\begin{array}{l}
r^{14}(2r-1)(r-1)^4(2r+1)^7(9r^3+r^2-12r-6)^2k^8-2r^{12}\left(r-1\right)^2(2r+1)^5(9r^3+r^2-12r-6)(54r^{10}+1320r^9-1504r^8-3773r^7+2471r^6 \\
+4698r^5-820r^4-2577r^3-447r^2+348r+102)k^7-r^{10}(2r+1)^3(+17496r^{19}-185328r^{18}-1550628r^{17}+3376963r^{16}+8424132r^{15}- \\
12448517r^{14}-23543530r^{13}+19318572r^{12}+39953496r^{11}-10965942r^{10}-40501692r^9-5506489r^8+21923232r^7+10448935r^6 \\
-4148542r^5-4391914r^4-737988r^3+335940r^2+148536r+16884)k^6+2r^8(2r+1)^2(565704r^{21}-3244968r^{20}-19571574r^{19}+ \\
28372986r^{18}+129630757r^{17}-61236857r^{16}-405959310r^{15}-51105532r^{14}+680962024r^{13}+403006748r^{12}-563227388r^{11}- \\
651023966r^{10}+88681765r^9+439656951r^8+181293426r^7-79258032r^6-95058314r^5-28874218r^4+1247670r^3+2954280r^2 \\
+719208r+59616)k^5-r^6(2r+1)(139968r^{24}+31218696r^{23}-112946076r^{22}-759964382r^{21}+467113423r^{20}+4998381772r^{19} \\
+1700624430r^{18}-14609799124r^{17}-14326332121r^{16}+18777959426r^{15}+35381771786r^{14}-835543402r^{13}-38683141955r^{12}- \\
24675749216r^{11}+12699021338r^{10}+23477430128r^9+8645610845r^8-4223507878r^7-5530025046r^6-2343196436r^5- \\
377845552r^4+58808688r^3+38585472r^2+6908544r+457344)k^4+2r^4(35r^4+20r^3-47r^2-48r-12)(93312r^{22}+6797520r^{21} \\
-18233964r^{20}-127308714r^{19}+20259166r^{18}+667003990r^{17}+503202983r^{16}-1372437504r^{15}-2140701783r^{14}+594759834r^{13} \\
+3293173206r^{12}+1828131494r^{11}-1549879480r^{10}-2449892286r^9-862137253r^8+543563516r^7+709389777r^6+337478350r^5 \\
+79471700r^4+4930104r^3-2079456r^2-518400r-38016)k^3-r^2(35r^4+20r^3-47r^2-48r-12)^2(46656r^{19}+1716660r^{18}- \\
4154118r^{17}-25297949r^{16}+2052128r^{15}+104262705r^{14}+84400528r^{13}-148459766r^{12}-255011732r^{11}-15606650r^{10}+238593422r^9 \\
+193678671r^8-817020r^7-93433211r^6-68413896r^5-24273724r^4-4369056r^3-226224r^2+42624r+5184)k^2+2r(3r+2)(35r^4 \\
+20r^3-47r^2-48r-12)^3(864r^{14}+19314r^{13}-55772r^{12}-201489r^{11}+109489r^{10}+642387r^9+247737r^8-699283r^7-733621r^6+ \\
2823r^5+393735r^4+269016r^3+80976r^2+10944r+432)k-3(r+1)(3r+2)^2(r^2-3r-2)(35r^4+20r^3-47r^2-48r-12)^4(8r^6+ \\
137r^5-92r^4-276r^3+30r^2+171r+54)
\end{array}\right).$$