"Green" managerial delegation theory

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ONLINE APPENDIX

Welfare analysis

This section complements the analysis provided in the main text by considering the consequences of the government's decision about the size of the welfare-maximising emissions tax and the firms' strategic interactions on the overall social welfare (by considering only equilibrium outcomes). Substituting out the expression of the optimal tax rates (5), (13) and (25) in the main text into the corresponding social welfare functions, one gets the post-tax equilibrium social welfare functions in the three symmetric scenarios, (GD,GD), (PM,PM), and (SD,SD), which are given as follows:

$SW^{*SD/SD} = \frac{16(2g+1)}{98g+33} > SW^{*GD/GD} = SW^{*PM/PM} = \frac{5(2g+1)}{32g+11}$, for any g.

This comparison implicitly assumes that $0.20138 < g < 1.2727$. Indeed, only in this range of values of g is the comparison amongst the three games analysed in the main text meaningful. Then, the equation above shows that the equilibrium social welfare function in each scenario is a monotonic decreasing function of g, and the sales delegation contract under abatement (SD,SD) leads to the highest possible social welfare. This is because the post-tax consumer surplus is the highest in that case as the strategic profile SD contributes to fostering production dramatically compared to the other contracts after the government has chosen the optimal tax.

It is preliminarily interesting now to discuss the unexpected reason why the "green" managerial delegation leaves social welfare unchanged compared to the profit maximisation contract. Interestingly, though managers are partially incentivised to increase emissions, there is no trade-off between employment and production on the one hand and environmental protection on the other hand by comparing GD versus PM. Indeed, social welfare is the same regardless of whether abatement choices are taken by owners under profit maximisation (PM,PM) or managers under "green" delegation (GD,GD).

Further analytical inspection reveals that the consumer surplus and the environmental damage are equal under the two symmetric regimes, i.e., GD/GD and PM/PM. However, the pre-tax output in the two scenarios (GD,GD) and (PM,PM) are different. As owners can delegate to managers abatement decisions through an appropriate incentive contract based on emissions, the government chooses the emissions tax rates such that the post-tax output is identical under the two regimes as the optimal tax rate under "green" delegation is higher than the optimal tax rate under profit maximisation. This means that there exists a simple transfer of resources between the government (in terms of tax revenues, because of the different tax rates in the two regimes) and firms (in terms of profits, because of the symmetrical more/less tax savings effect), flowing from the latter to the former, leaving social welfare unchanged. Indeed, the difference between the optimal emissions tax rate under GD and the optimal emissions tax rate under PM is exactly equal to the incentive designed by the owner about the emissions chosen by the "green" manager who is remunerated through an incentive based on emissions.

In addition, the emissions tax rate under GD is the highest. This implies a higher incentive for managers under sales delegation to abate more than managers under "green" delegation as the bonus that managers can obtain under standard sales delegation is larger than the corresponding value under the designing of an eco-friendly managerial contract based on emissions instead of sales. This may apparently let the GD contract work as an anti-ecological device.

However, the environmental damage under SD/SD is larger than under GD/GD because of the incentive of the SD contract created on the side of output production. *This is the essence for defining our contract as "green" delegation*. On the one hand, firms save more on taxation (marginal cost) under SD/SD than firms can do under GD/GD because of a higher abatement choice that managers can get in the former case. On the other hand, the sharp post-tax output increase greatly reduces the market price and total revenues under SD/SD, and this contributes to reducing the market price, causing the post-tax equilibrium profits under SD to fall below the post-tax equilibrium profits under GD. Definitively, due to the large increase in production, the environmental damage in the SD/SD regime is the largest. In summary, by setting the appropriate tax rates, the strategic interactions between firms lead the government to achieve the highest social welfare under SD/SD, in contrast to the firms' interests. This allows us to conclude that, in the parameter range of g where SD/SD emerges as a Nash equilibrium, social welfare is the highest, though firms are entrapped in a prisoner's dilemma regardless of whether SD is chosen over GD or PM. Following the discussion so far, figures A1-A3 help illustrate these results by contrasting the equilibrium welfare-maximising tax rate (figure A1), the environmental damage (figure A2) and social welfare (figure A3) in the three symmetric regimes GD, PM, and SD for $0.20138 < g < 1.2727$.

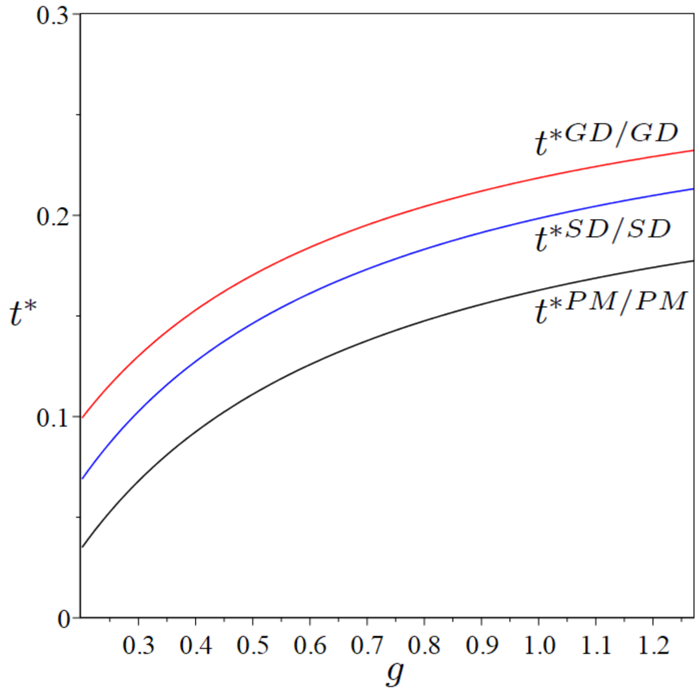

Figure A1. Equilibrium welfare-maximising tax rate in the three regimes for $0.20138 < g < 1.2727$.

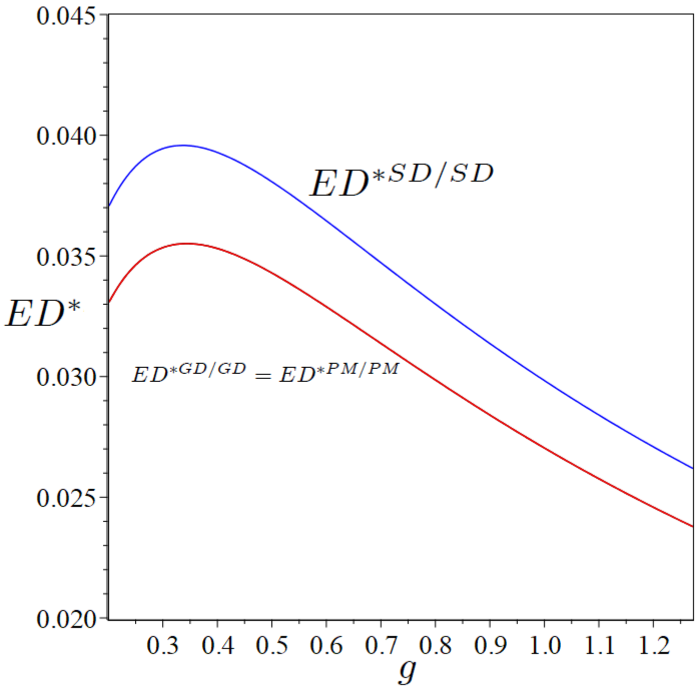

Figure A2. Equilibrium environmental damage in the three regimes for $0.20138 < g < 1.2727$.

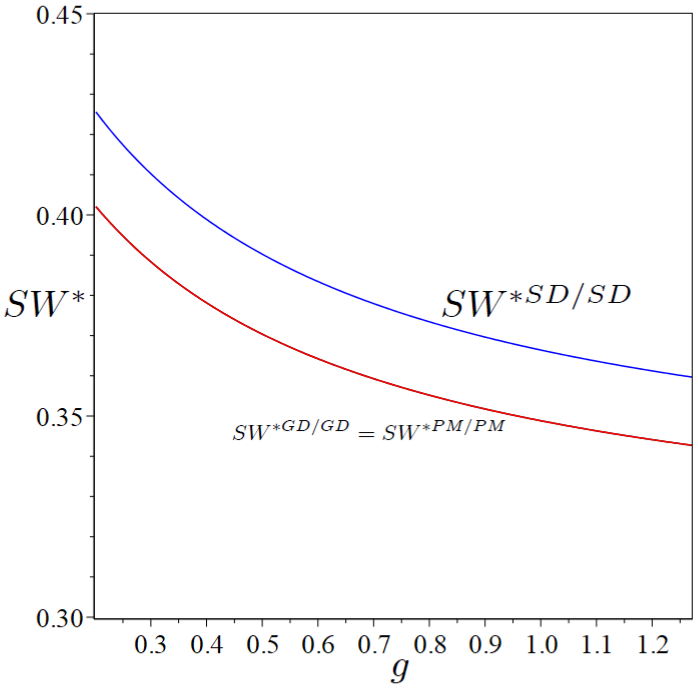

Figure A3. Equilibrium social welfare in the three regimes for $0.20138 < g < 1.2727$.

Finally, we note that there is no Pareto-efficient equilibrium outcomes for the overall society. The delegation contract based on emissions, however, leads to a reduction in environmental damage, and thus its design encourages the improvement of public education systems for the achievement of an eco-responsible attitude.

It is now important to compare GD and SD. Combining the post-tax equilibrium welfare equations with those of the post-tax equilibrium environmental damage under GD allows us to pinpoint the existence of a trade-off between environmental quality on the one hand and employment (production) and social welfare on the other with respect to SD. This is the standard trade-off that often emerges, unfortunately, in the environmental economics literature. Indeed, the larger production (employment) and consumers' surplus are associated with greater pollution, increasing the environmental damage. These results are essentially due to the increase in the emissions tax of the GD contract. Our analysis reveals that the anti-eco-friendly outcome is given by the emergence of (SD,SD) as the Pareto inefficient Nash equilibrium of the game GD versus SD, whereby while jointly both firms could agree to play GD they are unilaterally better off playing SD with damage improving social welfare but worsening the environment.

Appendix A. Analytical details

This appendix shows that the results of the article hold also when one assumes that the abating technology allows one to eliminate emissions entirely. In doing so, we consider the maximisation problem of the PM firm for reasons of analytical tractability, but the same results arise in the cases of GD and SD. Assuming emissions cannot be eliminated entirely, (e.g., $0 \leq k_i < q_i$) is supported by the stylised fact that an abatement technology allowing a firm to completely abate pollutant from industrial production does not exist in the real world. Results of our models, however, do not change assuming an abating technology such that $0 \leq k_i \leq q_i$.

In this regard, the profit maximisation problem for firm i ($i = 1,2, \quad i \neq j$) at the second stage of the game can be written as:

$$\max_{\{q_i, k_i\}} \pi_i(q_i, q_j, k_i) = (1 - q_i - q_j)q_i - t(q_i - k_i) - z\frac{k_i^2}{2}.$$
$$s.t. \quad q_i - k_i \geq 0$$

The Lagrangian function for this problem is:

$$\mathrm{L} = (1 - q_i - q_j)q_i - t(q_i - k_i) - z\frac{k_i^2}{2} + \lambda(q_i - k_i).$$

According to the Kuhn-Tucker conditions, the optimal level of output and pollution abatement must satisfy the following constraints:

$$\begin{aligned}
&\frac{\partial \mathrm{L}}{\partial q_i} = \frac{\partial \pi_i}{\partial q_i} + \lambda \leq 0, \quad q_i \geq 0 \quad \text{and} \quad q_i \frac{\partial \mathrm{L}}{\partial q_i} = 0 \\
&\frac{\partial \mathrm{L}}{\partial k_i} = \frac{\partial \pi_i}{\partial k_i} + \lambda \leq 0, \quad k_i \geq 0 \quad \text{and} \quad k_i \frac{\partial \mathrm{L}}{\partial k_i} = 0 \quad . \\
&\frac{\partial \mathrm{L}}{\partial \lambda} = q_i - k_i \geq 0, \quad \lambda \geq 0, \quad \text{and} \quad \lambda \frac{\partial \mathrm{L}}{\partial \lambda} = 0
\end{aligned}$$

If $\lambda > 0$, then $\frac{\partial \mathrm{L}}{\partial \lambda} = 0$ so that $q_i - k_i = 0 \Rightarrow q_i = k_i$, and both $\frac{\partial \pi_i}{\partial q_i} < 0$ and $\frac{\partial \pi_i}{\partial k_i} < 0$. If $\lambda = 0$, then $\frac{\partial \mathrm{L}}{\partial \lambda} > 0$ so that $q_i - k_i > 0 \Rightarrow q_i > k_i$, and both $\frac{\partial \pi_i}{\partial q_i} = 0$ and $\frac{\partial \pi_i}{\partial k_i} = 0$. Therefore, given the Kuhn–Tucker conditions, the firm's profit maximisation with respect to k_i allows us to derive the following optimal emission intensity:

$$k_i = \frac{t}{z} > 0 \text{ if } t > 0 \quad \text{or} \quad k_i = 0 \text{ if } t = 0.$$

The former represents the interior solution of the problem, whereas the latter is a corner solution. Moreover, it can be easily shown that the second-order conditions for a maximum $\frac{\partial^2 \pi_i}{\partial q_i^2} < 0$ and $\frac{\partial^2 \pi_i}{\partial k_i^2} < 0$ are fulfilled.

Appendix B. Analytical details and proofs of lemmas, propositions and results

This appendix reports the expressions of several equations used in sections 4, 5 and 6 of the main paper and the proofs of the corresponding lemmas, propositions and results.

Both firms are profit maximisers (PM/PM)

$$PS^{PM/PM} = \pi_1^{PM/PM} + \pi_2^{PM/PM} = \frac{1}{9}(2 - 4t + 11t^2), \quad \text{(A1)}$$

$$CS^{PM/PM} = \frac{(q_1^{PM/PM} + q_2^{PM/PM})^2}{2} = \frac{2}{9}(1 - t)^2, \quad \text{(A2)}$$

$$TR^{PM/PM} = t(e_1^{PM/PM} + e_2^{PM/PM}) = \frac{2}{3}t(1 - 4t), \quad \text{(A3)}$$

$$\boldsymbol{ED^{PM/PM} = \frac{g}{2}(e_1^{PM/PM} + e_2^{PM/PM})^2 = \frac{2}{9}g(1 - 4t)^2}. \quad \text{(A4)}$$

Proof of Lemma 1. Lemma 1 follows immediately from the expressions in (A1)-(A4).

Proof of Proposition 1. The welfare-maximising tax rate under PM/PM is obtained by computing the derivative $\frac{\partial SW^{PM/PM}}{\partial t} = 0 \Rightarrow t^{*PM/PM} = \frac{8g-1}{32g+11}$. Then, $t^{*PM/PM} > 0$ if and only if $g > 1/8 = 0.125$ and $t^{*PM/PM} < 1$ is fulfilled for any $g > 0$.

Both firms are "green" delegated (GD/GD)

$$PS^{GD/GD} = \pi_1^{GD/GD} + \pi_2^{GD/GD} = \frac{39}{196} - \frac{39}{98}t + \frac{236}{196}t^2, \quad \text{(A5)}$$

$$CS^{GD/GD} = \frac{(q_1^{GD/GD} + q_2^{GD/GD})^2}{2} = \frac{25}{98}(1 - t)^2, \quad \text{(A6)}$$

$$TR^{GD/GD} = t(e_1^{GD/GD} + e_2^{GD/GD}) = \frac{2}{7}t(3 - 10t), \quad \text{(A7)}$$

$$\boldsymbol{ED^{GD/GD} = \frac{g}{2}(e_1^{GD/GD} + e_2^{GD/GD})^2 = \frac{2}{49}g(3 - 10t)^2}. \quad \text{(A8)}$$

Proof of Lemma 2. Lemma 2 follows immediately from the expressions in (A5)-(A8).

Proof of Proposition 2. The welfare-maximising tax rate under GD/GD is obtained by computing the derivative $\frac{\partial SW^{GD/GD}}{\partial t} = 0 \Rightarrow t^{*GD/GD} = \frac{48g-1}{5(32g+11)}$. Then, $t^{*GD/GD} > 0$ if and only if $g > 1/48 = 0.020833$ and $t^{*GD/GD} < 1$ is fulfilled for any $g > 0$.

Firm 1 is "green" delegated, and firm 2 is profit maximiser (GD/PM)

$$PS^{GD/PM} = \pi_1^{GD/PM} + \pi_2^{GD/PM} = \frac{71}{338} - \frac{71}{169}t + \frac{409}{338}t^2, \tag{A9}$$

$$CS^{GD/PM} = \frac{(q_1^{GD/PM} + q_2^{GD/PM})^2}{2} = \frac{81}{338}(1-t)^2, \tag{A10}$$

$$TR^{GD/PM} = t(e_1^{GD/PM} + e_2^{GD/PM}) = \frac{2}{13}t(5-18t) =, \tag{A11}$$

$$\boldsymbol{ED^{GD/PM}} = \boldsymbol{\frac{g}{2}}(\boldsymbol{e_1^{GD/PM}} + \boldsymbol{e_2^{GD/PM}})^2 = \boldsymbol{\frac{2}{169}g(5-18t)^2}. \tag{A12}$$

Proof of Lemma 3. Lemma 3 follows immediately from the expressions in (A9)-(A12).

Proof of Proposition 3. The welfare-maximising tax rate under GD/PM is obtained by computing the derivative $\frac{\partial SW^{GD/PM}}{\partial t} = 0 \Rightarrow t^{*GD/PM} = \frac{180g-11}{648g+223}$. Then, $t^{*GD/PM} > 0$ if and only if $g > 11/180 = 0.06111$ and $t^{*GD/PM} < 1$ is fulfilled for any $g > 0$.

Both firms are sales delegated (SD/SD)

$$PS^{SD/SD} = \pi_1^{SD/SD} + \pi_2^{SD/SD} = \frac{4}{25} - \frac{8}{25}t + \frac{29}{25}t^2, \tag{A13}$$

$$CS^{SD/SD} = \frac{(q_1^{SD/SD} + q_2^{SD/SD})^2}{2} = \frac{8}{25}(1-t)^2, \tag{A14}$$

$$TR^{SD/SD} = t(e_1^{SD/SD} + e_2^{SD/SD}) = \frac{2}{5}t(2-7t), \tag{A15}$$

$$\boldsymbol{ED^{SD/SD}} = \boldsymbol{\frac{g}{2}}(\boldsymbol{e_1^{SD/SD}} + \boldsymbol{e_2^{SD/SD}})^2 = \boldsymbol{\frac{2}{25}g(2-7t)^2}. \tag{A16}$$

Proof of Lemma 4. Lemma 4 follows immediately from the expressions in (A13)-(A16).

Proof of Proposition 4. The welfare-maximising tax rate under SD/SD is obtained by computing the derivative $\frac{\partial SW^{SD/SD}}{\partial t} = 0 \Rightarrow t^{*SD/SD} = \frac{2(14g-1)}{98g+33}$. Then, $t^{*SD/SD} > 0$ if and only if $g > 1/14 = 0.07142$ and $t^{*SD/SD} < 1$ is fulfilled for any $g > 0$.

Firm 1 is sales delegated, and firm 2 is profit maximiser (SD/PM)

$$PS^{SD/PM} = \pi_1^{SD/PM} + \pi_2^{SD/PM} = \frac{3}{16} - \frac{3}{8}t + \frac{19}{16}t^2, \tag{A17}$$

$$CS^{SD/PM} = \frac{(q_1^{SD/PM} + q_2^{SD/PM})^2}{2} = \frac{9}{32}(1-t)^2, \tag{A18}$$

$$TR^{SD/PM} = t(e_1^{SD/PM} + e_2^{SD/PM}) = \frac{1}{4}t(3-11t), \tag{A19}$$

$$\boldsymbol{ED^{SD/PM}} = \boldsymbol{\frac{g}{2}(e_1^{SD/PM} + e_2^{SD/PM})^2} = \boldsymbol{\frac{1}{32}g(3-11t)^2}. \tag{A20}$$

Proof of Lemma 5. Lemma 5 follows immediately from the expressions in (A17)-(A20).

Proof of Proposition 5. The welfare-maximising tax rate under SD/PM is obtained by computing the derivative $\frac{\partial SW^{SD/PM}}{\partial t} = 0 \Rightarrow t^{*SD/PM} = \frac{3(11g-1)}{121g+41}$. Then, $t^{*SD/PM} > 0$ if and only if $g > 1/11 = 0.0909$ and $t^{*SD/PM} < 1$ is fulfilled for any $g > 0$.

Firm 1 is "green" delegated, and firm 2 is sales delegated (GD/SD)

$$PS^{GD/SD} = \pi_1^{GD/SD} + \pi_2^{GD/SD} = \frac{103}{578} - \frac{103}{289}t + \frac{681}{578}t^2, \tag{A21}$$

$$CS^{GD/SD} = \frac{(q_1^{GD/SD} + q_2^{GD/SD})^2}{2} = \frac{169}{578}(1-t)^2, \tag{A22}$$

$$TR^{GD/SD} = t(e_1^{GD/SD} + e_2^{GD/SD}) = \frac{2}{17}t(7-24t), \tag{A23}$$

$$\boldsymbol{ED^{GD/SD}} = \boldsymbol{\frac{g}{2}(e_1^{GD/SD} + e_2^{GD/SD})^2} = \boldsymbol{\frac{2}{289}g(7-24t)^2}. \tag{A24}$$

Proof of Lemma 6. Lemma 6 follows immediately from the expressions in (A21)-(A24).

Proof of Proposition 6. The welfare-maximising tax rate under GD/SD is obtained by computing the derivative $\frac{\partial SW^{GD/SD}}{\partial t} = 0 \Rightarrow t^{*GD/SD} = \frac{336g-17}{1152g+391}$. Then, $t^{*GD/SD} > 0$ if and only if $g > 0.0506$ and $t^{*GD/SD} < 1$ is fulfilled for any $g > 0$.

Proofs of Results 1, 2 and 3

Proof of Result 1. Knowing that

$\Delta\pi_a = \frac{2(2g+1)(539136g^3+177408g^2-73600g-24365)}{(648g+223)^2(32g+11)^2}$,

$\Delta\pi_b = \frac{-4(2g+1)(311040g^3+180864g^2+15983g-3243)}{(648g+223)^2(32g+11)^2}$ and

$\Delta\pi_c = \frac{4(2g+1)}{(32g+11)^2}$, it follows that 1) $\Delta\pi_a < 0$, $\Delta\pi_b < 0$ and $\Delta\pi_c > 0$ if $0.20138 < g < 0.37$, and 2) $\Delta\pi_a > 0$, $\Delta\pi_b < 0$ and $\Delta\pi_c > 0$ if $0.37 < g < 2.305$.

Proof of Result 2. Knowing that

$\Delta\pi_a = \frac{2(2g+1)(35816g^3+27654g^2+8328g+1045)}{(121g+41)^2(32g+11)^2}$,

$\Delta\pi_b = \frac{-(2g+1)(1600830g^3+1547931g^2+526312g+62861)}{2(121g+41)^2(98g+33)^2}$ and

$\Delta\pi_c = \frac{(2g+1)(119168g^3+203168g^2+89826g+11737)}{2(32g+11)^2(98g+33)^2}$, it follows that $\Delta\pi_a > 0$, $\Delta\pi_b < 0$ and $\Delta\pi_c > 0$ for any $0.125 < g < 1.2727$.

Proof of Result 3. Knowing that

$\Delta\pi_a = \frac{-(2g+1)(66834432g^3+86436672g^2+38733614g+5798183)}{2(1152g+391)^2(98g+33)^2}$,

$\Delta\pi_b = \frac{8(2g+1)(368640g^3+509952g^2+254402g+42093)}{(1152g+391)^2(32g+11)^2}$ and

$\Delta\pi_c = \frac{-(2g+1)(119168g^3+126336g^2+38082g+3025)}{2(98g+33)^2(32g+11)^2}$, it follows that $\Delta\pi_a < 0$, $\Delta\pi_b > 0$ and $\Delta\pi_c < 0$ for any $0.1423 < g < 3.3541$.

Appendix C. Horizontal product differentiation

This appendix aims to check the robustness of the results of the basic model developed in the main text by considering a quantity-setting duopoly with horizontal product differentiation, as in Singh and Vives (1984). The indirect market demand of firm $i = 1,2$ under product differentiation reads as $p_i = 1 - q_i - dq_j$, $i, j = 1,2$, $i \neq j$, where p_i denotes the price of product of variety i, q_i, and q_j as the quantities produced by firm i and firm j, respectively, and $-1 \leq d \leq 1$ measures the degree of product differentiation. Positive (resp. negative) values of d refer to product substitutability (resp. complementarity). When $d = 0$ goods are totally differentiated, each firm is a monopolist for its own product. The case $d = 1$ resembles the analysis developed in the main text (homogeneous products). Therefore, firm i's profit functions become $\pi_i = (1 - q_i - dq_j)q_i - t(q_i - k_i) - \frac{z}{2}k_i^2$, $i, j = 1,2$, $i \neq j$ $(z = 1)$. Applying the standard optimisation techniques and solving each game backwards, one can first derive the firms' payoffs for every game related to 1) GD versus PM, 2) SD versus PM, and 3) GD versus SD. For economy of space, the analytical derivations are not reported, but they are available upon request from the authors. Making use of the payoffs related to the corresponding cases under horizontal product differentiation, one can compute the profit differentials as in (20), (31) and (36) along with the relevant constraints, as is shown in figures A4-A6 – plotted in the parameter space (g, d) – which are related to GD versus PM, SD versus PM, and GD versus SD, respectively. The red and green curves bound the red and green areas of technical non-feasibility in figures A4-A6. Indeed, feasibility (the white areas in the figures) requires $g > g_T^1(d)$ and $g < g_T^2(d)$ for any $-1 \leq d \leq 1$, respectively.

GD versus PM with horizontal product differentiation. Figure A4 shows in the parameter space (g, d) the Nash equilibria of the game GD versus PM under Cournot competition with differentiated products and emissions' abatement. The profit differentials in (20) generate three regions under product substitutability (regions A, B and C) and one region under product complementarity (region D). The feasible parameter space is bounded by the (red) curve

$$g_T^1(d) = \frac{-d^7+3d^6+7d^5-35d^4+60d^3+24d^2-288d+288}{(3+d)(3d^3-7d^2-12d+24)(2d^3-5d^2-12d+24)},$$

and by the (green) curve

$$g_T^2(d) = \frac{3d^7-5d^6-64d^5+94d^4+438d^3-588d^2-864d+1152}{d^2(3+d)(3-d)(2d^3-5d^2-12d+24)}.$$

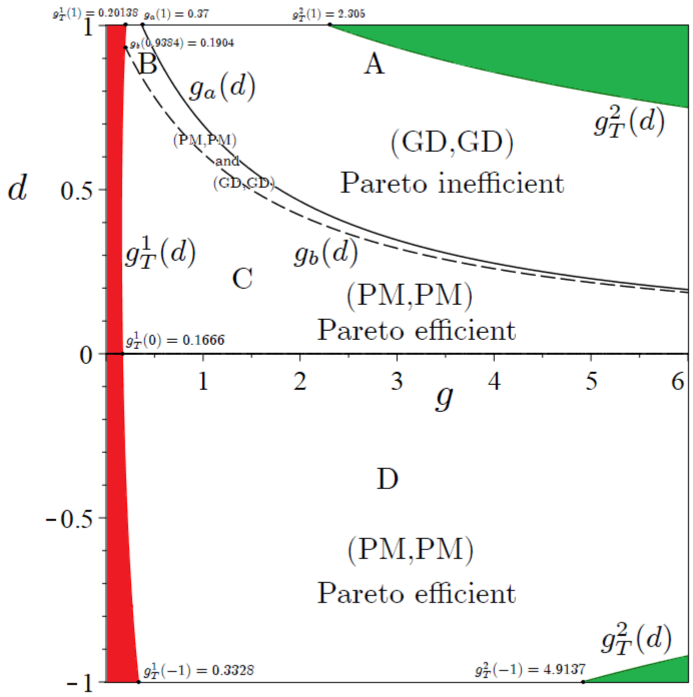

Figure A4. GD versus PM. Nash equilibria in the parameter space (g, d).

The red curve $g_T^1(d)$ bounds from below the red area, requiring that the societal awareness toward a clean environment (alternatively, against the damage generated by industrial production) be high enough to ensure positive levels of pollution abatement for the managerial firm in the asymmetric subgame in which the owner of one firm designs a "green" delegation contract to its own manager (GD), and the rival is profit maximising (PM) under abatement. The green curve $g_T^2(d)$ bounds from above the green area, requiring that the societal awareness toward a clean environment (alternatively, against the damage generated by industrial production) be low enough to guarantee that $e_i \geq 0$ for the PM firm in the asymmetric subgame. In the white areas of figure A4 (representing feasibility of the game GD versus PM), all other relevant constraints are satisfied and apply accordingly.

Region A shows that designing a "green" delegation contract represents a dominant strategy, and the Nash equilibrium of this non-cooperative game is (GD,GD). However, this equilibrium is Pareto inefficient so that firms are cast into a prisoner's dilemma and there exist conflicts between self-interest and mutual benefit to become a "green"-delegated firm. In region B, both (PM,PM) and (GD,GD) arise as pure-strategy Nash equilibria of the non-cooperative (coordination) game, but the PM payoff dominates GD. Finally, region C shows the existence of (PM,PM) as the unique Pareto efficient pure-strategy Nash equilibrium, so that the game becomes an anti-prisoner's dilemma (deadlock) in that case. This outcome also holds under product complementarity (region D). Therefore, the main tenets of Result 1 shown in the main text of this article also hold under product differentiation, with the additional finding that (PM,PM) emerges as the unique Pareto-efficient Nash equilibrium when products are sufficiently differentiated under product substitutability (the result is confirmed under product complementarity). This is because product differentiation works in an anti-ecological direction by increasing profits under PM, thus requiring larger levels of societal awareness (and this in turn implies a higher environmental tax rate) for a firm to become "green" delegated.

SD versus PM with horizontal product differentiation. Figure A5 shows in the parameter space (g, d) the Nash equilibria of the classical sales delegation game, i.e., SD versus PM, under Cournot competition with differentiated products augmented with emissions' abatement. The profit differentials in (31) generate three regions under product substitutability (regions A, B and C) and three regions under product complementarity (regions D, E, and the small blue quasi-triangular area in the south-west of figure A5). The feasible parameter space is bounded by the (red) curve

$g_T^1(d) = \frac{1}{2(3+d)}$,

and by the (green) curve

$g_T^2(d) = \frac{2(4d^4+17d^3-30d^2-48d+64)}{d^2(-9d^2-4d+24)}$.

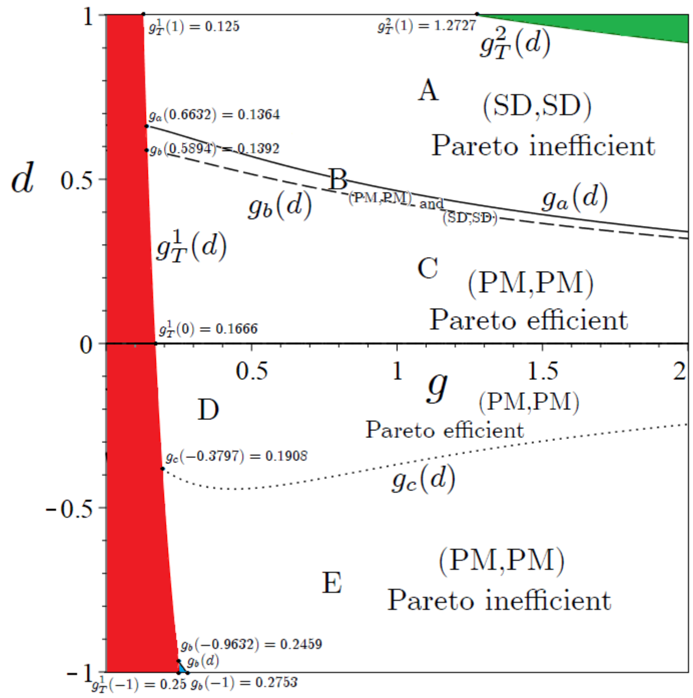

Figure A5. SD versus PM. Nash equilibria in the parameter space (g, d).

The red curve $g_T^1(d)$ bounds from below the red area, requiring that societal awareness toward a clean environment (alternatively, against the damage generated by industrial production) should be high enough to ensure a positive welfare-maximising tax rate and positive levels of pollution abatement for each profit-maximising firm in the symmetric subgame in which both players are PM under abatement. The green curve $g_T^2(d)$ bounds from above the green area, requiring that the societal awareness toward a clean environment (alternatively, against the damage generated by industrial production) should be low enough to guarantee that $e_i \geq 0$ for the profit-maximising firm in the asymmetric subgame in which the owner of one firm designs a standard sales delegation contract to its own manager (SD) and the rival is profit maximising (PM). In the white areas of figure A5 (representing feasibility of the game SD versus PM), all other relevant constraints are satisfied and apply accordingly.

Region A shows the emergence of the standard prisoner's dilemma, as was detailed in Vickers (1985), Sklivas (1987), and Fershtman and Judd (1987) without abatement, in which (SD,SD) emerges as the unique Pareto-inefficient Nash equilibrium of the non-cooperative game SD versus PM under abatement so that designing a sales delegation contract represents a dominant strategy. Therefore, there exist conflicts between self-interest and mutual benefit to become sales-delegated firms. In region B, both (PM,PM) and (SD,SD) arise as pure-strategy Nash equilibria of the non-cooperative (coordination) game, but the PM payoff dominates SD. Finally, in region C, (PM,PM) is the unique Pareto-efficient pure-strategy Nash equilibrium, so that the game becomes an anti-prisoner's dilemma (deadlock). This result is of relevance because, with differentiated products and pollution abatement, the standard result of the emergence of strategic sales delegation and the Prisoner's Dilemma Structure of the game obtained in Fershtman and Judd (1987) is completely reversed (see Fanti *et al*., 2017a, 2017b, for an extensive treatment of several results that can be obtained in the managerial delegation theory framed in strategic competitive contexts). These results confirm the main tenets of Result 2 in the main text (referred to as the case of homogeneous products) that still hold in a wide area (region A) in the parameter space (g, d). However, product differentiation causes dramatic changes in the equilibrium outcomes of the game. Indeed, when products become sufficiently differentiated under product substitutability, (PM,PM) arises as the unique, Pareto-efficient equilibrium, in line with Fanti *et al*. (2017b). This allows us to conclude that product differentiation works in an anti-delegation and anti-ecological direction by increasing profits under PM so that larger levels of societal awareness are indeed necessary for a firm to become sales delegated under abatement. Under product complementarity, the equilibrium outcome is (PM,PM) for most of the parameter space, and the larger product complementarity makes it likely that the game will fall into the area of Pareto inefficiency (prisoner's dilemma). However, when products tend to be perfect complements and the degree of societal awareness against environmental damages is sufficiently low (the small quasi-triangular blue portion in the south-west section of figure A5), there is a coordination game in which (PM,PM) and (SD,SD) are pure-strategy Nash equilibria, but the SD payoff dominates PM.

GD versus SD with horizontal product differentiation. Figure A6 shows in the parameter space (g, d) the Nash equilibria of the game GD versus SD under Cournot competition with differentiated products augmented with emissions abatement. The profit differentials in (36) generate two regions under product substitutability (regions A and B) and one region under product complementarity (region C). The feasible parameter space is bounded by the (red) curve

$$g_T^1(d) = \frac{-3d^8+2d^7+26d^6-52d^5-28d^4+336d^3-240d^2-576d+576}{2(2+d)^2(2-d)(-d^2+3d+6)(5d^3-9d^2-24d+36)},$$

and by the (green) curve

$$g_T^2(d) = \frac{2d^8+13d^7-64d^6-218d^5+548d^4+1128d^3-1824d^2-1728d+2304}{2d^3(2+d)(5d^3-9d^2-24d+36)}.$$

The red curve $g_T^1(d)$ bounds from below the red area, requiring that the societal awareness toward a clean environment (alternatively, against the damage generated by industrial production) be high enough to ensure positive levels of pollution abatement for the "green" delegated firm in the asymmetric subgame in which the owner of one firm designs a delegation contract based on emissions to its own manager (GD) and the owner of the rival firm designs a standard sales delegation contract (SD) under abatement. The green curve $g_T^2(d)$ bounds from above the green area, requiring that the societal awareness toward a clean environment (alternatively, against the damage generated by industrial production) be low enough to guarantee that $e_i \geq 0$ for the "green" delegated firm in the asymmetric subgame. In the white areas of figure A6 (representing feasibility of the game GD versus SD), all other relevant constraints are satisfied and apply accordingly.

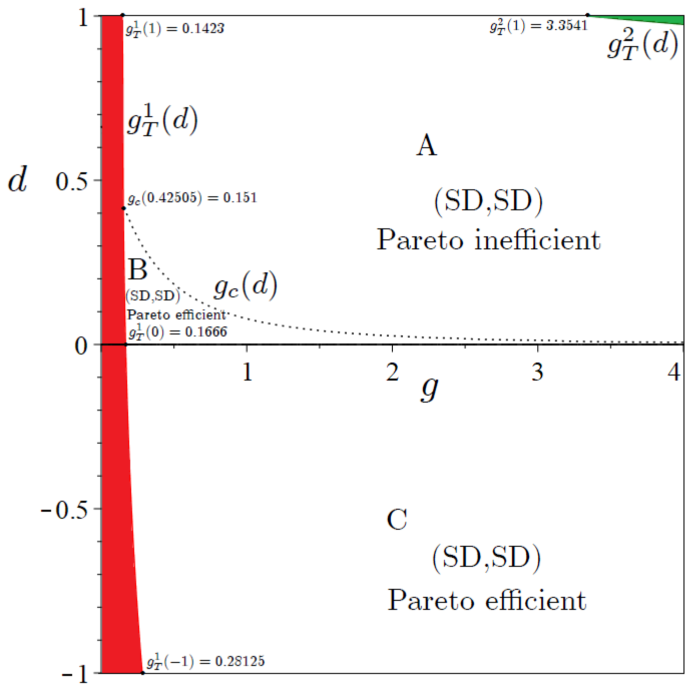

Figure A6. GD versus SD. Nash equilibria in the parameter space (g, d).

Figure A6 shows that (SD,SD) always emerges as the unique pure-strategy Nash equilibrium of the game. This implies that SD represents the owners' dominant strategy, regardless of both the degree of product differentiation and societal awareness against environmental damages. The Nash equilibrium (SD,SD) is Pareto inefficient (prisoner's dilemma) in region A, i.e., when the degree of product differentiation under product substitutability is sufficiently low. In this case, there is conflict between self-interest and mutual benefit to become sales delegated when the owners can choose between hiring ether a “green” manager or a sales-delegated manager. When the degree of product substitutability becomes larger (region B), the game becomes a deadlock so that the prisoner’s dilemma is solved, and there is no conflict between self-interest and mutual benefit to become sales delegated. This result is confirmed under product complementarity. Result 3 presented in the main text therefore still holds under product differentiation.

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