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Hirose, Kosuke and Matsumura, Toshihiro

Osaka University of Economics, Osaka, Japan, The University of Tokyo, Tokyo, Japan

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Green Transformation in Oligopoly Markets under Common Ownership*

Kosuke Hirose† and Toshihiro Matsumura‡

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Abstract

A theoretical investigation is conducted on how common ownership (or the extent of cooperation in an industry) affects firms' incentives to adopt green fuel in an oligopoly. The findings show that common ownership hinders the switch from brown to green fuels in two ways. First, an increase in the degree of common ownership reduces a firm's incentive to adopt green fuel. Second, an increase in the degree of common ownership induces a production substitution from green to brown fuel firms. Both these effects reduce the share of green fuel.

JEL classification codes: M14, Q57, L13

Keywords: green transition, green fuel, brown fuel, competition restricting effect, production substitution

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† Corresponding author: Osaka University of Economics, 2-2-8, Ohsumi, Higashiyodogawa-Ku, Osaka 533-8533, Japan. E-mail: hirose@osaka-ue.ac.jp

‡Institute of Social Science, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan. Phone:(81)-3-5841-4932. Fax:(81)-3-5841-4905. E-mail:matsumur@iss.u-tokyo.ac.jp, ORCID:0000-0003-0572-6516

1 Introduction

In the presence of the serious risk of climate change and vulnerabilities in the supply of fossil fuels, green transformation (GX) has become increasingly critical and attracted significant attention from academic researchers, policymakers, and businesspersons (Victor, 2022).

The European Union (EU) continues to lead the world in GX. Despite facing an energy crisis, the EU has repeatedly declared its commitment to GX. It presented a new report in May 2022, entitled "REPowerEU" stating that "the green transformation will strengthen economic growth, security, and climate action for Europe and our partners."[1] Although Japan has been lagging in GX, it has rapidly adopted it. In September 2021, the University of Tokyo, a leading university in Japan, declared that it has adopted GX as one of the pillars of its action plan; this also includes leading international GX and collaborating with local communities.[2] In February 2022, the Japanese Ministry of Economy, Trade and Industry (METI) announced the GX League Basic Concept and called for companies to endorse it. METI has committed to collaborating with the endorsing companies to prepare for putting the GX League into full-scale operation, and to realize a net zero-emission society by 2050.[3]

The GX of the economy requires strong commitments from both governments and firms to a green transition that will reduce and respond to environmental degradation. In particular, the role of large oligopolistic firms in GX is especially important. One of the most important elements of GX is the combination of electrification and switching from fossil fuel power generation to zero emission green generation, such as PV, wind power, hydropower, and geothermal power generation.[4] Some industries in which electrification is difficult or costly would continue to exist in the future, such as energy, steel, cement, shipping, aviation, chemical, and foundry related industries. Firms in such industries, typically those that

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[1] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

[2] https://www.u-tokyo.ac.jp/en/about/gx.html

[3] https://www.meti.go.jp/english/press/2022/0201_001.html

[4] See Ino and Matsumura (2019) for more details of this discussion and a policy combination that promotes electrification and reduces emission intensity.

are oligopolistic, will continue consuming fuel. Thus, a fuel shift, or switching from fossil fuel to zero-emission fuels including green hydrogen, ammonia, synthetic fuel, biofuel, and sustainable aviation fuel, is a key issue for GX.[5]

Some empirical findings suggest that the valuation from financial markets is regarded as a major determinant of firms' voluntary commitment to GX (Margolis et al. 2007; Jacobs, 2014). This aspect will become increasingly important as green and sustainable funds grow globally.[6]

Another distinct feature of recent financial markets has been the high concentration of the investment industry. The growth of financial markets has led institutional investors, such as Vanguard, BlackRock, State Street, and Fidelity to hold substantial shares in major listed firms that compete in the same industries (common ownership).[7] If these competing firms are concerned about the interests of their common owners, they are indirectly concerned about the profits of the other firms too. Hence, they may deviate from profit-maximizing behavior.[8] Moreno and Petrakis (2022) use their dynamic model to show that all stationary equilibria involve large common investors holding symmetric portfolios, regardless of whether the firms face price or quantity competition.

Common ownership among competing firms may affect their behavior and yield anti-competitive outcomes (Moreno and Petrakis, 2022). As a result, common ownership has become a central issue in recent debates on antitrust policies. Some empirical studies show that this has a substantial effect on the strategic behavior of firms held by institutional

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[5] Firms are already beginning to adopt green fuels. For example, A.P. Moller– Maersk, a giant firm in the shipping industry, committed to adopting green fuels and achieving net-zero emission logistics by 2040 (https://www.maersk.com/). JERA and Tokyo Gas, major energy companies in Japan, committed to replacing fossil fuels with ammonia and synthetic fuels (Hirose and Matsumura, 2021).

[6] For example, sustainable funds in the United States (US) have grown substantially. See https://www.morningstar.com/articles/1019195/a-broken-record-ows-for-us-sustainable-funds-again-reach-new-heights

[7] BlackRock, Vanguard, and State Street are the top three institutional investors that own more than 10% of the shares in listed firms globally. They are often the largest stockholders of many listed firms (Nikkei Market News, 2018/10/24).

[8] In addition, several firms in the same industry hold minor shares in other firms (Farrell and Shapiro, 1990; Gilo et al., 2006; Reynolds and Snapp, 1986).

stockholders.[9]

In this study, we focus on firms' commitment to GX and theoretically investigate their incentives for switching from brown to green fuel in the context of oligopolies having common ownership. A firm's switch to green fuel improves its reputation in the financial and product markets, and potentially resulting in monetary gains. However, green fuel may be more expensive than brown. Thus, the fuel switch may increase a firm's marginal costs. Each firm considers this trade-off when choosing to commit to switch to green fuel. Specifically, we investigate how the degree of common ownership affects the incentives for switching fuel and the share of green fuel.

We find that common ownership hinders the switch from brown to green fuel in two ways. First, common ownership reduces the incentive to adopt green fuel. Therefore, an increase in the degree of common ownership raises hurdles for realizing a green equilibrium where all firms commit to a green fuel switch. Second, an increase in the degree of common ownership induces production substitution from green fuel firms to brown ones only when a proper subset of firms commit to switching to green fuel. Both these effects reduce the share of green fuel. In other words, we find a negative effect of common ownership on GX – something not previously shown in the literature.

The remainder of this paper is organized as follows: In Section 2, we briefly review the related literature. Section 3 presents the model. Section 4 details the equilibrium analysis. Sections 5 and 6 present the results and a welfare analysis, respectively. The conclusions are summarized in Section 7 while the relevant proofs can be found in Appendix.

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[9] See Backus et al. (2021) for an example of the rise in common ownership in the U.S., and Schmalz (2018) for a review of empirical studies that suggest links between common ownership and firms' behavior. For antitrust concerns, see Elhauge (2016).

2 Related literature

GX has been extensively discussed in the literature with particular emphasis on the role played by green finance and green innovation (Schiederig et al., 2012; Victor, 2022). Especially, there is a growing literature that examines the incentives for green technologies (Montero, 2002; Lambertini et al., 2017; Li, 2017; McDonald and Poyago-Theotoky, 2017). In this study, we focus on the switching from fossil fuel to green fuel. In oligopolies, this stage occurs after the development of related green technologies. This switching stage in oligopoly markets has rarely been examined in the theoretical literature on GX. More importantly, this is the first study to investigate the relationship between green fuel choice and the degree of common ownership.

As the literature shows, green finance and consumers' concerns about firms' green activities have increased the incentives for firms to engage in green actions (Baron, 2001; Innes, 2006; Margolis et al. 2007; Jacobs, 2014; Liu et al., 2015; Akomea-Frimpong et al., 2021). In the present study, we incorporate these ideas into an oligopoly model and investigate whether a recent trend in the financial market — common ownership — accelerates or reduces the incentive to switch to green fuels.

The literature on common ownership has become increasingly popular and diverse. While common ownership softens competition in the product or service markets and raises prices, partial ownership by common owners in the same industry may lead firms to internalize industry-wide externalities and improve welfare. López and Vives (2019) show a possible inverted relationship between the degree of common ownership and welfare. Common ownership internalizes the positive externality of R&D. When the degree of common ownership is small, this welfare-improving effect may negate welfare-harming (competition-reducing) effect. Sato and Matsumura (2020) investigate a free entry market and find that common ownership internalizes the business-stealing effect. As a result, moderate common ownership may improve welfare.[10] They also show that significant common ownership reduces welfare. Chen et al. (2021) investigate a vertically related market. They demonstrate that common ownership mitigates the inefficiency due to double marginalization. This welfare-improving effect negates the welfare-harming, competition-reducing effect in a downstream market, particularly if competition among the downstream firms is weak. However, no study has analyzed the relationship between common ownership and GX. This study is the first to investigate GX in the context of fuel choice in oligopoly markets under common ownership.

Hirose and Matsumura (2022) have investigated the relationship between common ownership and environmental corporate social responsibility. They show that a moderate degree of common ownership promotes environmental corporate responsibility and reduces emissions, whereas a significant degree of common ownership harms welfare.[11] However, they have only focused on end-of-pipe abatement with the initial emission assumed to be proportional to production. Thus, they neither discuss GX nor fuel choice.

3 The Model

We formulate a duopoly model, in which each firm i ($i = 1, 2$) chooses whether to switch from brown fuels (e.g., fossil fuel) to green fuels (e.g., green hydrogen).

The demand function is given by $p = a - bQ$, where p is the product price, a and b are positive constants, and $Q = q_1 + q_2$ is the total output of both firms.

Prior to making a production decision, each firm faces a choice of fuel to be used to produce outputs. Green fuel is more expensive than brown fuel; thus, the marginal cost for the firm choosing green fuel, c^G, is higher than that for the firm choosing brown fuel, c^B, where $c^G > c^B$ are nonnegative constants. Committing to use green fuel improves the reputation of the firm; thus, the firm obtains a reputational gain of $F > 0$.[12] We normalize

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[10] See Mankiw and Whinston (1986) for a discussion on the business-stealing effect in free entry markets.

[11] For a discussion on environmental corporate responsibility, see Poyago-Theotoky and Yong (2019), Lee and Park (2019), Fukuda and Ouchida (2020), Hirose et al. (2020), and Xu et al. (2022).

[12] See Margolis et al. (2007) for the rationalization of this approach. Alternatively, we can assume that

c^B as zero and denote $c^G = c$. It is assumed that a/c is sufficiently large.[13] Therefore, firm i's profit is $\pi_i^G = (a - bQ - c)q_i + F$ if it is a green firm that chooses green fuel, and $\pi_i^B = (a - bQ)q_i$ if it is a brown firm that chooses brown fuel.

Following the recent theoretical literature on common ownership (López and Vives, 2019), we assume that each firm i has the following objective function:

$$\psi_i = \pi_i + \lambda \pi_j,$$

where π_i is firm i's profit, π_j is its rival's profit, and λ denotes the degree of common ownership.[14]

The game proceeds as follows: In the first stage, each firm i independently chooses whether to use green or brown fuel. In the second stage, after observing the rival's fuel choice, each firm i independently chooses q_i (Cournot competition).

4 Analysis

We solve the game using backward induction. In the second stage, given the fuel choice, each firm i independently chooses q_i. The first-order condition for firm i is

$$a - b(q_i + q_j) - bq_i - c_i - \lambda b q_j = 0 \ (i, j = 1, 2, \ i \neq j), \tag{1}$$

where $c_i = c$ if firm i is a green firm, and $c_i = 0$ if it is a brown firm.

From these first-order conditions, we obtain the following reaction function in the second

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a firm using brown fuel bears a fixed cost as a result of reputational loss, consumer boycott, or countering these negative effects. As our aim is to analyze the impact of common ownership on GX, we abstract away from the strategic implications of private politics. See Baron (2001) and Innes(2006) for a description of the interaction between green technology adoption and private politics.

[13] If $a/c < 2$, the firm that chooses brown fuel monopolizes the market when the rival chooses green fuel. Thus, we need $a/c > 2$ for the analysis that follows.

[14] Prior studies have also investigated this type of payoff interdependence using a coefficient of cooperation model (Cyert and Degroot, 1973; Escrihuela-Villar, 2015) and relative profit maximization model (Escrihuela-Villar and Gutiérrez-Hita, 2019; Hamamura, 2021; Matsumura and Matsushima, 2012; Matsumura et al., 2013).

stage:

$$R_i(q_j) = \frac{a - c_i - (1+\lambda)bq_j}{2b}. \tag{2}$$

From (2), we determine that the strategies in the second stage are strategic substitutes regardless of λ.

From the reaction functions of the two firms, we identify the following equilibrium output in the second stage:[15]

$$q_i = \frac{(1-\lambda)a - 2c_i + (1+\lambda)c_j}{b(1-\lambda)(3+\lambda)}. \tag{3}$$

To ensure interior solutions (i.e., to ensure positive outputs for both firms), we assume

$$\lambda < \bar{\lambda} := \frac{a-2c}{a}. \tag{4}$$

In other words, our attention is focused on the case in which λ is not too large.

Let $\psi(GG)$ be the equilibrium payoff of each firm when both firms choose green fuel, $\psi(BB)$ be the equilibrium payoff of each firm when both firms choose brown fuel, $\psi(BG)$ be the equilibrium payoff of a brown firm when the rival is a green firm, and $\psi(GB)$ be the equilibrium payoff of a green firm when the rival is a brown firm. From (3), we determine the following equilibrium payoff for four subgames:

$$\begin{aligned}
\psi(GG) &= (1+\lambda)\left(\frac{(a-c)^2(1+\lambda)}{b(3+\lambda)^2} + F\right), && (5)\\
\psi(BB) &= \frac{(1+\lambda)^2 a^2}{b(3+\lambda)^2}, && (6)\\
\psi(BG) &= \frac{(a(1-\lambda)+c(1+\lambda))(a+a\lambda+c)}{b(1-\lambda)(3+\lambda)^2} \\
&\quad +\lambda\left\{\frac{a^2(1-\lambda^2) - ac(4+\lambda-\lambda^2) + 2c^2(2+\lambda)}{b(1-\lambda)(3+\lambda)^2} + F\right\}, && (7)\\
\psi(GB) &= \frac{a^2(1-\lambda^2) - ac(4+\lambda-\lambda^2) + 2c^2(2+\lambda)}{b(1-\lambda)(3+\lambda)^2} + F \\
&\quad +\lambda\left\{\frac{(a(1-\lambda)+c(1+\lambda))(a+a\lambda+c)}{b(1-\lambda)(3+\lambda)^2}\right\}. && (8)
\end{aligned}$$

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[15] The second-order conditions are satisfied throughout this study.

In the first stage, each firm independently chooses green or brown fuel. There are three possible pure strategy equilibrium patterns. The equilibrium in which both firms choose green fuel (i.e., green equilibrium) exists if and only if $\psi(GG) \geq \psi(BG)$, the equilibrium in which no firm chooses green fuel (i.e., brown equilibrium) exists if and only if $\psi(BB) \geq \psi(GB)$, and the equilibrium in which only one firm chooses green fuel (i.e., asymmetric equilibrium) exists if and only if $\psi(BG) \geq \psi(GG)$ and $\psi(GB) \geq \psi(BB)$.

5 Results

First, we characterize the equilibrium pattern of fuel choice.

Lemma 1 *(i) Green equilibrium exists if and only if*

$$F \geq F_G := \frac{c((1-\lambda)a + \lambda c)(4 + \lambda(3+\lambda))}{b(1-\lambda)(3+\lambda)^2}.$$

(ii) Brown equilibrium exists if and only if

$$F \leq F_B := \frac{c((1-\lambda)a - c)(4 + \lambda(3+\lambda))}{b(1-\lambda)(3+\lambda)^2}$$

and $F_B < F_G$.

(iii) Asymmetric equilibrium exists if and only if $F \in [F_B, F_G]$.

Proof See Appendix.

Lemma 1 is intuitive. When F (the gain from being a green firm) is sufficiently large, both firms become green firms. When F is small, no firm adopts green fuel. When F is neither too small nor too large, only one firm adopts green fuel.

We now present our main findings addressing the relationship between the degree of common ownership and fuel choice.

Proposition 1 *(i)* F_G *increases with* λ. *(ii)* F_B *increases with* λ *if and only if* $a/c > H(\lambda)$, *where*

$$H(\lambda) := \frac{\lambda^3 + 3\lambda^2 + 15\lambda + 13}{(1-\lambda)^2(1+3\lambda)}.$$

(iii) $H(\lambda)$ *increases with* λ. *(iv)* $H(\bar{\lambda}) > a/c$.

Proof See Appendix.

Proposition 1(i) is our main result, which implies that the green equilibrium (wherein all firms choose green fuel) is less likely to appear when the degree of common ownership is higher. In other words, common ownership hinders the realization of the green equilibrium.

The implications of Proposition 1(ii-iv) are less clear than those of Proposition 1(i). Proposition 1(ii-iv) implies the following: F_B may or may not increase with λ when λ is small, and F_B decreases with λ when λ is large (close to $\bar{\lambda}$). F_B monotonically decreases with λ if a/c is small (Figure 1a). F_B has an inverted-U shape otherwise (Figure 1b).[16] Thus, if a/c is large, an increase in λ does not promote the brown equilibrium. However, if a/c is small, an increase in λ may promote a switch from the brown equilibrium to an asymmetric equilibrium, particularly when λ is small.

In summary, an increase in λ always hinders the green equilibrium, whereas it is ambiguous if it promotes or hinders the brown equilibrium. We explain the intuition behind this proposition after presenting the other key results — Propositions 2 and 3 — which help clarify the underlying mechanism of Proposition 1.

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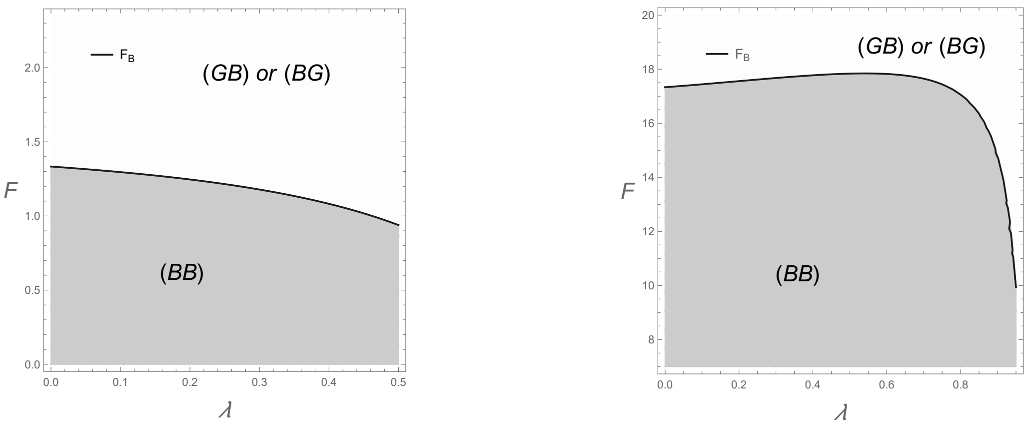
[16] As $H(\bar{\lambda}) > a/c$ and $H(\lambda)$ is continuous, F_B decreases with λ when λ is close to $\bar{\lambda}$. In other words, F_B never monotonically increases with λ.



$(a) : a = 40, b = c = 1$ $(b) : a = 4, b = c = 1$

Figure 1: Region in which the brown equilibrium exists

Let $q(B, B)$ and $q(G, G)$ represent each firm's equilibrium output for the brown and green equilibria, respectively. Let $q(B, G)$ ($q(G, B)$) represent the equilibrium output of the brown (green) firm when the rival is a green (brown) firm.

Proposition 2 *(i) $q(G, G)$, $q(B, B)$, and $q(G, B)$ decrease with λ. (ii) $q(B, G)$ decreases with λ if and only if*

$$\frac{a}{c} > I(\lambda) := \frac{\lambda^2 + 2\lambda + 5}{(1 - \lambda)^2}$$

and $I(\lambda)$ increases with λ. (iii) $q(G, B)/q(B, G)$ decreases with λ.

Proof See the Appendix.

When both firms are green or brown (i.e., the firms are symmetric), an increase in the degree of common ownership reduces each firm's output. When λ is larger, each firm is more concerned about its rival's profit. Thus, an increase in λ reduces each firm's output and increases its rival's profit. Therefore, Proposition 2(i) is both natural and intuitive.

However, under asymmetry, an increase in λ may stimulate the brown firm's production, which seems counterintuitive. This is because the brown firm's production is more efficient than the green firm's from the viewpoint of joint-profit maximization. When λ is larger, the equilibrium combination of the outputs is close to the cooperative (joint-profit-maximizing) one. Thus, the green firm has a stronger incentive than the brown firm to reduce its output. As the strategies in the second stage are strategic substitutes, a reduction in the green firm's output naturally increases the brown firm's output. This strategic effect can be strong, especially when c is large, and may dominate the standard output-reduction effect due to common ownership. Consequently, the brown firm's output may increase with λ.

Even when $q(B,G)$ decreases with λ, the output-reducing effect of common ownership is stronger for the green firm than for the brown firm. This leads to Proposition 2(iii).

Proposition 3 is a natural conjecture from Proposition 2(iii).

Proposition 3

$$\frac{\partial\psi(G,B)}{\partial\lambda} < \frac{\partial\psi(B,G)}{\partial\lambda}$$

holds if and only if

$$F > F_3 := \frac{(2a-c)c}{b(3+\lambda)^2}$$

and $F_3 < F_B$.

Proof See Appendix.

Proposition 3 states that an increase in λ is more beneficial for a brown firm than for a green one unless F is too small. Note that the asymmetric equilibrium exists only when $F \geq F_B$ and $F_B > F_3$. As Proposition 2 states, an increase in λ increases the brown firm's market share, which implies that an asymmetric situation leads to a more significant increase in the brown firm's profit.

We now explain the intuition behind Proposition 1. First, we explain the intuition behind Proposition 1(i), which is our main result. Proposition 1(i) states that the green equilibrium is less likely to appear when λ is larger.

Proposition 3 states that common ownership increases the brown firm's profit more significantly than that of the green firm. Given that the rival firm is a green firm, there is a stronger incentive to keep the firm brown because this induces a smaller output for the rival, which in turn increases both the firm's own profit and the joint profit of the two firms.

Second, we explain Proposition 1(ii-iv), which suggests that F_B may increase with λ when λ is small, but F_B decreases with λ when λ is large.

Suppose that λ is small and thus, each firm is primarily concerned with its own profit. Let us suppose that firm 2 chooses brown. If firm 1 chooses green, firm 1 is exploited by firm 2 because a production substitution occurs from firm 1 to firm 2.[17] An increase in λ strengthens this effect. Therefore, a marginal increase in λ from zero may increase F_B. However, when λ is large, this production substitution becomes beneficial even for the green firm because it is strongly concerned with its rival's profit and this production substitution increases the rival's profit. Thus, F_B decreases with λ when λ is large.

To check the robustness of our main finding, we will briefly discuss an n-firm oligopoly case. If there are n firms, there are $n+1$ equilibrium patterns, and the analysis becomes intractable. However, we can show that the green equilibrium in which all firms choose green fuel exists if and only if $F \geq F_{nG}$, where

$$F_{nG} = \frac{c\left(c\left((\lambda-1)\lambda^2+(\lambda+1)\left(\lambda^2+1\right)n^2-2\left(\lambda^3+1\right)n\right)-a(\lambda-1)\left(\lambda\left(n^2-1\right)+\lambda^2(n-1)^2+2n\right)\right)}{b(1-\lambda)(\lambda(n-1)+n+1)^2}.$$

F_{nG} increases with λ. Thus, the green equilibrium is less likely to appear when λ is large, as shown in Proposition(i). To realize GX, it is imperative that all firms in important industries choose green fuel. Therefore, our result suggests that common ownership or cooperative payoffs in the industry can be an obstacle for achieving GX.

Further, Propositions 2 and 3 still hold in the oligopoly case. Thus, our main results are applicable to oligopoly markets and not limited to duopoly markets alone.

Finally, we discuss what happens if an emission tax is introduced. An emission tax reduces the cost difference between green and brown fuels, which reduces both F_B and F_G. In other words, the green equilibrium (brown equilibrium) is more (less) likely to appear

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[17] See Lahiri and Ono (1988) for the welfare effects of production substitution.

as the tax rate increases. However, our results remain unchanged as long as the tax rate is moderate.[18]

6 Welfare

In this section, we briefly discuss the welfare implications of our results. We assume that the emission function is $e_i = hq_i$, and that for environmental damage is $D = r(e_1 + e_2)^2$. Welfare is defined as

$$\begin{aligned} W &= \int_0^Q p(q)dq - pQ + \sum_{n=1}^{2} \pi_i - D(E) \\ &= a(q_1 + q_2) - b\frac{(q_1 + q_2)^2}{2} - \sum_{n=1}^{2} c_i q_i + \sum_{n=1}^{2} F_i - r(e_1 + e_2)^2, \end{aligned} \tag{9}$$

where $(c_i, F_i, e_i) = (c, F, 0)$ if firm i is a green firm and $(c_i, F_i, e_i) = (0, 0, hq_i)$ if it is a brown firm.

Once again, we discuss a duopoly model. As we discussed in the previous section, there are three equilibrium patterns. Given the equilibrium pattern, λ affects the outputs of both firms and thus, affects welfare.

Proposition 4 *(i) If the equilibrium pattern is green, an increase in λ reduces welfare. (ii) If the equilibrium pattern is either brown or asymmetric, an increase in λ may or may not improve welfare.*

Proof See Appendix.

An increase in λ reduces the total output, which harms consumer welfare. However, it also reduces emissions, which reduces the consequent damage. The former (latter) effect overshadows the latter (former) effect when r is small (large); thus, welfare may or may not increases with λ, unless the equilibrium pattern is green. In the green equilibrium, there

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[18] If the tax rate is set so high that brown fuel becomes more expensive, then all firms will adopt green fuel regardless of λ.

are no emissions; thus, the latter effect does not exist. Thus, an increase in λ always harms welfare.

The equilibrium pattern is not given exogenously. Even a marginal change in λ may change it. Thus, a slight change in λ can affect welfare discontinuously. We can observe this by investigating welfare when $F = F_G$ and $F = F_B$, wherein two equilibria exist.

Proposition 5 *(i) When $F = F_B$, the asymmetric equilibrium yields greater welfare than the brown equilibrium. (ii) When $F = F_G$, the green equilibrium may or may not yield greater welfare than the asymmetric equilibrium.*

Proof See Appendix.

Suppose that F is close to but not equal to F_B. Then, a small change in λ may change the equilibrium pattern from brown to asymmetric. This reduces emissions and improves welfare. Moreover, this stimulates the production of the brown firm, and thus, the effect on consumer surplus is limited. Therefore, this change always improves welfare. This yields Proposition 5(i). Figure 2 depicts the relationship between welfare and λ when F is close to F_B.[19]

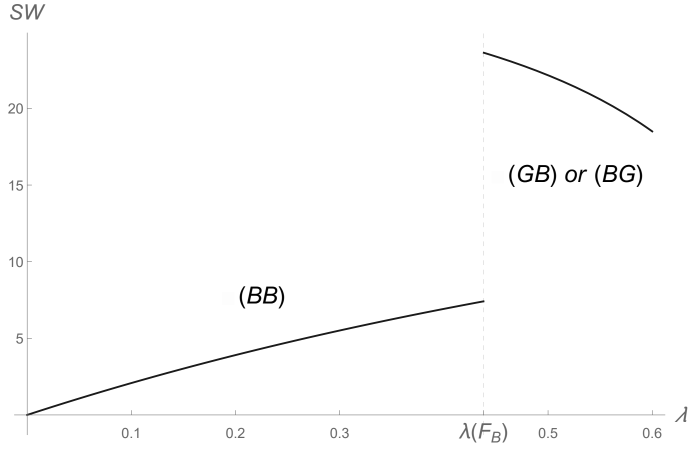

Figure 2: Discontinuous welfare change by the switch from brown to asymmetric equilibrium

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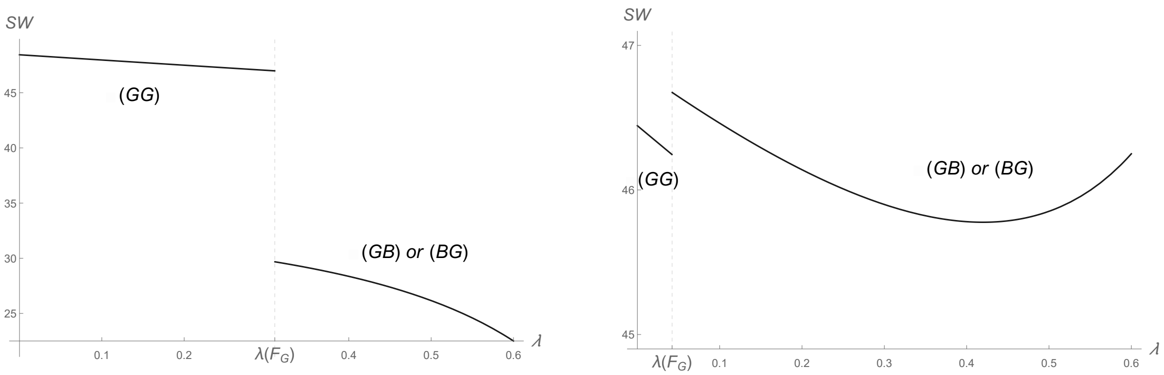
[19] We set $a = 10, c = 2, b = 1, h = 1, r = 1, F = 10$ in Figure 2.

Suppose that F is close to but not equal to F_G. Then, a decrease in λ may change the equilibrium pattern from asymmetric to green. This reduces emissions and improves welfare. In contrast, because a low cost firm disappears, the total output reduces substantially. This harms consumer welfare. The former (latter) effect dominates the latter (former) effect when r is large (small). Thus, welfare may or may not increase with λ. Figure 3a (Figure 3b) corresponds to the welfare improving (reducing) change from an asymmetric equilibrium to a green equilibrium.[20] However, it is natural to assume that r is large considering the serious risk of climate change. Therefore, we can say that an increase in λ is likely to harm welfare because it hinders the realization of the green equilibrium.



$(a)\ r = 1$

$(b)\ r = 1/100$

Figure 3: Discontinuous welfare change by the switch from asymmetric to green equilibrium

7 Conclusion

In this study, we investigate how common ownership affects GX in an oligopoly market. Common ownership creates two effects that hinder GX. First, an increase in common ownership creates a hurdle for realizing a green equilibrium wherein all firms switch from brown to green fuel. Second, common ownership induces production substitution from green to brown firms, thus reducing the share of green fuel. It is known that common ownership

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[20] We set $a = 10, c = 2, b = 1, h = 1, r = 1, F = 10$ in Figure 3a and $a = 10, c = 2, b = 1, h = 1, r = 1/100, F = 9$ in Figure 3b.

reduces firms' output and harms consumer welfare. We show that common ownership has another negative effect — a harmful effect on GX. Thus, common ownership should not only be monitored from an antitrust perspective, but also from an environmental viewpoint.

In this study, we focus on the fuel choice of firms. However, firms may engage in energy-saving and/or make emission-abatement investments. Moreover, we do not consider emission taxes, which inherently promote GX. Extending our analysis to include other environmental activities and policies remains a topic for future research.[21] Further, we assume that the number of firms is given exogenously. It is known that firms' behavior and optimal environmental policies differ in free-entry markets (Katsoulacos and Xepapadeas, 1995; Lee, 1999; Lahiri and Ono, 2007; Matsumura and Yamagishi, 2017). Thus, extending our analysis to free-entry markets also remains a topic for future research.

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[21] For recent discussions on these topics in the context of oligopolies, see Holland (2012), Lambertini et al. (2017), McDonald and Poyago-Theotoky (2017), Ino and Matsumura (2021), Hirose and Matsumura (2020), and Xu et al. (2022), and the papers cited therein.

Appendix

Proof of Lemma 1

(i) From (5) and (7), we have

$$\psi(GG) - \psi(BG) = -\frac{c((1-\lambda)a + \lambda c)(4 + \lambda(3+\lambda))}{b(1-\lambda)(3+\lambda)^2} + F. \tag{10}$$

Thus, $\psi(GG) \geq \psi(BG)$ holds if and only if

$$F \geq \frac{c((1-\lambda)a + \lambda c)(4 + \lambda(3+\lambda))}{b(1-\lambda)(3+\lambda)^2} \, (:= F_G)\, . \tag{11}$$

This implies Lemma 1(i).

(ii) From (6) and (8), we have

$$\psi(BB) - \psi(GB) = \frac{c((1-\lambda)a - c)(4 + \lambda(3+\lambda))}{b(1-\lambda)(3+\lambda)^2} - F. \tag{12}$$

Thus, $\psi(BB) \geq \psi(GB)$ holds if and only if

$$\frac{c((1-\lambda)a - c)(4 + \lambda(3+\lambda))}{b(1-\lambda)(3+\lambda)^2} \, (:= F_B) \geq F. \tag{13}$$

Comparing F_G and F_B, we have

$$F_G - F_B = \frac{c^2(4 + 7\lambda + 4\lambda^2 + \lambda^3)}{b(1-\lambda)(3+\lambda)^2} > 0.$$

This implies Lemma 1(ii).

(iii) From (10)–(12), we know that $\psi(BG) \geq \psi(GG)$ and $\psi(GB) \geq \psi(BB)$ hold if and only if $F_B \leq F \leq F_G$. This implies Lemma 1(iii). ■

Proof of Proposition 1

(i) Using (11), we obtain

$$\frac{\partial F_G}{\partial \lambda} = \frac{c\left(a(1+3\lambda)(1-\lambda)^2 + 2c\left(-\lambda^3 + 4\lambda^2 + 7\lambda + 6\right)\right)}{b(\lambda-1)^2(\lambda+3)^3} > 0.$$

(ii) Using (13), we obtain

$$\frac{\partial F_B}{\partial \lambda} = \frac{c\left(a(1-\lambda)^2(1+3\lambda) - c\left(\lambda^3+3\lambda^2+15\lambda+13\right)\right)}{b(1-\lambda)^2(\lambda+3)^3}.$$

Hence, we obtain

$$\frac{\partial F_B}{\partial \lambda} > 0 \text{ if and only if } \frac{a}{c} > \frac{\lambda^3+3\lambda^2+15\lambda+13}{(1-\lambda)^2(1+3\lambda)} (:= H(\lambda)).$$

(iii) We have

$$\frac{\partial H(\lambda)}{\partial \lambda} = \frac{2\left(7\lambda^3+51\lambda^2+69\lambda+1\right)}{(1-\lambda)^3(3\lambda+1)^2} > 0.$$

(iv) At $\lambda = \bar{\lambda}$, we obtain

$$H(\bar{\lambda}) = \frac{4a^3-6a^2c+3ac^2-c^3}{(2a-3c)c^2}.$$

We obtain

$$H(\bar{\lambda}) - \frac{a}{c} = \frac{4a^2(a-2c)+c^2(3a-c)}{(2a-3c)c^2} > 0.$$

Note that we assume $a/c > 2$. ■

Proof of Proposition 2

(i) By substituting $c_i = c_j = c$ into (3), we obtain

$$q(GG) = \frac{a-c}{b(3+\lambda)}. \tag{14}$$

From (14), we obtain

$$\frac{\partial q(GG)}{\partial \lambda} = -\frac{a-c}{b(3+\lambda)^2} < 0.$$

By substituting $c_i = c_j = 0$ into (3), we obtain

$$q(BB) = \frac{a}{b(3+\lambda)}. \tag{15}$$

From (15), we obtain

$$\frac{\partial q(BB)}{\partial \lambda} = -\frac{a}{b(3+\lambda)^2} < 0.$$

By substituting $(c_i, c_j) = (c, 0)$ into (3), we obtain

$$q(GB) = \frac{a(1-\lambda) - 2c}{b(3 - 2\lambda - \lambda^2)}. \tag{16}$$

From (16), we obtain

$$\frac{\partial q(GB)}{\partial \lambda} = -\frac{a(1-\lambda)^2 + 4c(1+\lambda)}{b(3-2\lambda-\lambda^2)^2} < 0.$$

(ii) From (3), we obtain

$$q(BG) = \frac{a(1-\lambda) + c(1+\lambda)}{b(3-2\lambda-\lambda^2)}. \tag{17}$$

From (17), we obtain

$$\frac{\partial q(BG)}{\partial \lambda} = -\frac{a(1-\lambda)^2 - c(5 + 2\lambda + \lambda^2)}{b(3-2\lambda-\lambda^2)^2}. \tag{18}$$

Hence,

$$\frac{\partial q(BG)}{\partial \lambda} \geq (<) 0 \text{ if and only if } \frac{a}{c} \leq (>) \frac{\lambda^2 + 2\lambda + 5}{(1-\lambda)^2} (:= I(\lambda)).$$

Moreover, we have

$$\frac{\partial I(\lambda)}{\partial \lambda} = \frac{4(3+\lambda)}{(1-\lambda)^3} > 0.$$

(iii) From (16) and (17), $q(GB)/q(BG)$ and its derivative with respect to λ are respectively

$$\begin{aligned} \frac{q(GB)}{q(BG)} &= \frac{a(1-\lambda) - 2c}{a(1-\lambda) + c(1+\lambda)}, \\ \frac{\partial(q(GB)/q(BG))}{\partial \lambda} &= -\frac{2c(2a-c)}{(a(1-\lambda) + c(1+\lambda))^2} < 0. \quad \blacksquare \end{aligned}$$

Proof of Proposition 3

From (7) and (8), we obtain

$$\begin{aligned} \frac{\partial \psi(BG)}{\partial \lambda} &= \frac{4a^2(1-\lambda)^2(1+\lambda) - ac(1-\lambda)^2(5\lambda+7) + 2c^2\left(\lambda^3 + 2\lambda^2 + 5\lambda + 8\right)}{b(1-\lambda)^2(\lambda+3)^3} + F, \\ \frac{\partial \psi(GB)}{\partial \lambda} &= \frac{4a^2(1-\lambda)^2(1+\lambda) - ac(1-\lambda)^2(3\lambda+1) + c^2\left(\lambda^3 + 3\lambda^2 + 15\lambda + 13\right)}{b(1-\lambda)^2(\lambda+3)^3}. \end{aligned}$$

Hence, we obtain

$$\frac{\partial\psi(BG)}{\partial\lambda}-\frac{\partial\psi(GB)}{\partial\lambda}=-\frac{(2a-c)c}{b(3+\lambda)^2}+F. \tag{19}$$

Thus, $(\partial\psi(BG))/(\partial\lambda) > (\partial\psi(GB))/(\partial\lambda)$ holds if and only if

$$F>\frac{(2a-c)c}{b(3+\lambda)^2}\,(:=F_3)\,. \tag{20}$$

From (13) and (20), we obtain

$$F_B-F_3=\frac{c(\lambda+1)\left(a\left(2-\lambda-\lambda^2\right)-c(\lambda+3)\right)}{b(1-\lambda)(\lambda+3)^2}>0. \quad \blacksquare$$

Proof of Proposition 4

(i) From (3) and (9), welfare in the green equilibrium is

$$W(GG)=\frac{2(a-c)^2(2+\lambda)}{b(3+\lambda)^2}+2F. \tag{21}$$

From (21), we obtain

$$\frac{\partial W(GG)}{\partial\lambda}=-\frac{2(a-c)^2(1+\lambda)}{b(3+\lambda)^3}<0.$$

(ii) Consider the brown equilibrium. Similarly, welfare in the brown equilibrium is

$$W(BB)=\frac{2a^2(b(2+\lambda)-2h^2r)}{b^2(3+\lambda)^2}. \tag{22}$$

From (22), we obtain

$$\frac{\partial W(BB)}{\partial\lambda}=-\frac{2a^2(b(1+\lambda)-4h^2r)}{b(3+\lambda)^3}>(<)0 \text{ if and only if } b(1+\lambda)<(>)4h^2r.$$

This implies that an increase in λ may or may not improve welfare when the equilibrium pattern is brown.

Next, consider the asymmetric equilibrium. Welfare in the asymmetric equilibrium is

$$W(BG)=\frac{H_1}{2b^2\left(\lambda^2+2\lambda-3\right)^2}, \tag{23}$$

where $H_1 = 2a^2(1-\lambda)^2(2b(\lambda+2)-h^2r) - 4ac(b(\lambda^3-3\lambda+2)-h^2(\lambda^2-1)r) - (c^2(b(5\lambda^2+6\lambda-11)+2h^2(1+\lambda)^2r))$. From (23), we obtain

$$\frac{\partial W(BG)}{\partial \lambda} = \frac{H_2}{b^2(3-2\lambda-\lambda^2)^3},$$

where $H_2 = 2a^2(\lambda-1)^3(b\lambda+b+h^2(-r)) - 2ac(b(\lambda-1)^3(\lambda+1) - 2h^2(\lambda^3+\lambda-2)r) - c^2(b(5\lambda^3+9\lambda^2-\lambda-13)+2h^2(\lambda^3+3\lambda^2+7\lambda+5)r)$.

Suppose that $a = 10, b = 1, c = 1, h = 1$ and $r = 10$. We have

$$\frac{\partial W(BG)}{\partial \lambda} = \frac{-180\lambda^4+1985\lambda^3-5931\lambda^2+5379\lambda-933}{(\lambda^2+2\lambda-3)^3} > 0 \text{ if and only if } 0 \leq \lambda \lessapprox 0.225.$$

This example shows that an increase in λ may or may not improve welfare when the equilibrium pattern is asymmetric. ■

Proof of Proposition 5

(i) From (22) and (23), the difference between $W(BG)$ and $W(BB)$ at $F = F_B$ is

$$\begin{aligned} &W(BG) - W(BB) \\ &= \frac{2h^2r\left(3a^2(1-\lambda)^2 - 2ac\left(1-\lambda^2\right) - c^2(\lambda+1)^2\right) + bc(1-\lambda)^2(2a\lambda(1+\lambda)+c(2\lambda+3))}{2b^2(1-\lambda)^2(\lambda+3)^2} > 0. \end{aligned}$$

(ii) From (21) and (23), the difference between $W(GG)$ and $W(BG)$ at $F = F_G$ is

$$W(GG) - W(BG) = \frac{2h^2r(a(\lambda-1)-c(\lambda+1))^2 - bc(\lambda-1)^2\left\{c\left(2\lambda^2+4\lambda+3\right)-2a\lambda(\lambda+1)\right\}}{2b^2(1-\lambda)^2(\lambda+3)^2}.$$

Suppose that $a = 10, b = 1, c = 1, h = 1$ and $r = 1/100$. We have

$$W(GG) - W(BG) = \frac{900\lambda^4-1000\lambda^3-769\lambda^2+902\lambda-29}{100(\lambda-1)^2(\lambda+3)^2} < 0 \text{ if and only if } 0 \leq \lambda \lessapprox 0.033.$$

This example shows that the green equilibrium may or may not yield greater welfare than the asymmetric equilibrium when $F = F_G$. ■

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Declarations

The authors declare that they have no conflicts of interest and that there are no financial or personal relationships with other individuals or organizations that could inappropriately influence our work.

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