# Modelling green innovation decision making with regulatory incentives and firm acquisitions

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# INTRODUCTION

- The need to address climate change is a major global concern and evolving preferences, regulations, and technologies create new market opportunities from green stakeholders, especially consumers.
- Consumers are increasingly aware of the impact that their consumption choices have and are paying more attention to sustainability. Thus, supplying green products is emerging as a firm strategy for reaching these environmentally conscious consumers (especially via vertical differentiation).
- Firms gain and sustain competitive advantage by developing long-term corporate technology strategies for acquiring technological resources. Yet, many firms are hesitant to conduct low-carbon innovation.
- Innovation can also be obtained via acquiring a firm that already owns the technology desired or has relevant know-how/production capabilities.

# INTRODUCTION

- Relying only on the market is not enough to allow social investment to reach optimal levels, given the multiple externalities of green technological innovation.

- Government incentives and regulations are needed to address market failures and barriers. The government must promote and guide firms to a low-carbon technological innovation path, using its ability to provide firms with optimal incentives to innovate.

- Although different regulations may have different effects on low-carbon technological innovation, the literature makes it clear that regulations can improve clean performance by affecting the costs and benefits of the environmental behavior of firms.

Chen et al. (2021); Fischer and Lyon (2014); Huang et al. (2019); Toolsema (2009); Wang et al. (2020).

# INTRODUCTION

- This paper explores green innovation impetus driven by market forces and incentives.

- Due to the multi-agent nature of the problem, game theory is used to assess low-carbon innovation decision-making by a firm and green consumption choices by a consumer. Both players are rational aiming at maximizing their payoffs and are representative of consumers and producers in the society.

# METHODOLOGY

## MODELS

- The models consist of consumer-firm games. Nash equilibria in both pure and mixed strategies are derived.

- 5 scenarios:
  i. No government intervention;
  ii. Government intervention: the consumer that chooses green receives a subsidy;
  iii. Government intervention: the government applies discriminatory policy to the firm;
  iv. Firm can acquire a startup in order to obtain the desirable green innovation, instead of investing in R&D and develop the innovation in-house;
  v. Sequential decision making: one side of the market observes the characteristics of the other side before making its own decision.

# METHODOLOGY

## BASE MODEL

Table 1 Representation of the strategic form game.

| | | Firm | |
|---|---|---|---|
| | | PG | PNG |
| Consumer | CG | $C_{11}, F_{11}$ | $C_{12}, F_{12}$ |
| | CNG | $C_{21}, F_{21}$ | $C_{22}, F_{22}$ |

Table 2 Payoffs for the consumer and the firm.

| Payoffs | |
|---|---|
| **Consumer** | $C_{11} = a$ |
| | $C_{12} = a - x_3$ |
| | $C_{21} = a - x_1$ |
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| **Firm** | $F_{11} = b - y$ |
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$a$ : consumer's base payoff

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| | $F_{21} = b - y - \boxed{z_1}$ |
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$a$ : consumer's base payoff

$x$ : utility loss (due to mismatch decisions & non-green purchase)

$b$ : firm's base payoff

$y$ : cost of innovating in low-carbon technologies

$z$ : revenue loss (due to mismatch between the product offered and the consumer's decision)

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*Table 3 Conditions for the payoffs order*

| **Consumer Payoffs** |
|---|
| $C_{11} > C_{21} > C_{22} > C_{12}$ ; $x_1 < x_2 < x_3$ |
| **Firm Payoffs** |
| $F_{22} > F_{11} > F_{21} > F_{12}$ ; $0 < y < z_2 - z_1$ |
| $F_{22} > F_{11} > F_{12} > F_{21}$ ; $z_2 - z_1 < y < z_2$ |
| $F_{22} > F_{12} > F_{11} > F_{21}$ ; $y > z_2$ |

$a$ : consumer's base payoff

$x$ : utility loss (due to mismatch decisions & non-green purchase)

$b$ : firm's base payoff

$y$ : cost of innovating in low-carbon technologies

$z$ : revenue loss (due to mismatch between the product offered and the consumer's decision

# RESULTS

## MODEL A – NO GOVERNMENT INTERVENTION

*Table 4 Representation of the strategic form game with the payoffs of model A.*

| | | Firm | |
|---|---|---|---|
| | | PG | PNG |
| Consumer | CG | $a, b - y$ | $a - x_3, b - z_2$ |
| | CNG | $a - x_1, b - y - z_1$ | $a - x_2, b$ |

- Solving the game in pure strategies:
  - No dominant strategy for the consumer;
  - If $y > z_2$, the firm's dominant strategy is to *Produce Non-Green*. The N.E. is $(CNG, PNG)$;
  - If $y < z_2$, the firm does not have a dominant strategy and there are two N.E.: $(CG, PG)$ and $(CNG, PNG)$.
- The N.E. depends on the relationship between $y$, how much it costs the firm to seek low-carbon innovation, and $z_2$, how much the company loses in terms of revenues when selling a non-green product to a consumer that has green behavior.

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| | CNG | $a-x_1, b-y-z_1$ | $a-x_2, b$ |

- Solving the game in mixed strategies:
  - Consumers adopt a green attitude with probability $\mathrm{p} = \frac{y+z_1}{z_1+z_2}$ and firms produce green with probability $\mathrm{q} = \frac{x_3-x_2}{x_3-x_2+x_1}$;
- The likelihood of consumers adopting a green attitude is increasing in $y$ and in $z_1$ and decreasing in $z_2$. The likelihood of firms producing green is increasing in $x_3$ and decreasing in $x_1$ and $x_2$.

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| | | Firm | |
|---|---|---|---|
| | | PG | PNG |
| Consumer | CG | $a, b - y$ | $a - x_3, b - z_2$ |
| | CNG | $a - x_1, b - y - z_1$ | $a - x_2, b$ |

Table 5 Sum of payoffs.

| | Sum of payoffs |
|---|---|
| $(CG; PG)$ | $a + b - y$ |
| $(CG; PNG)$ | $a - x_3 + b - z_2$ |
| $(CNG; PG)$ | $a - x_1 + b - y - z_1$ |
| $(CNG; PNG)$ | $a - x_2 + b$ |

- The best outcome for the two sides of the market is when both parties, consumers and producers, are aligned towards the same goal:
  - Welfare $(CNG, PNG)$ > Welfare $(CG, PNG)$ | Welfare $(CG, PG)$ > Welfare $(CNG, PG)$
- Total welfare when both players are green is higher than total welfare when both players are non-green if and only if $y < x_2$.

# RESULTS

## MODEL B1 –GOVERNMENT INTERVENTION: CONSUMER SUBSIDY POLICY

*Table 6 Representation of the strategic form game with the payoffs of model B1.*

| | | Firm | |
|---|---|---|---|
| | | PG | PNG |
| Consumer | CG | $a + s_C , b - y$ | $a - x_3 , b - z_2$ |
| | CNG | $a + s_C - x_1 , b - y - z_1$ | $a - x_2 , b$ |

- Now the payoffs of the consumer also include the subsidy parameter ($s_C$).

- The pure strategies solution for this game is the same as in model A and the mixed strategies solution for this game is also the same as in model A, showing that giving a subsidy to the consumption of green goods does not affect the consumer's and firm's decisions.

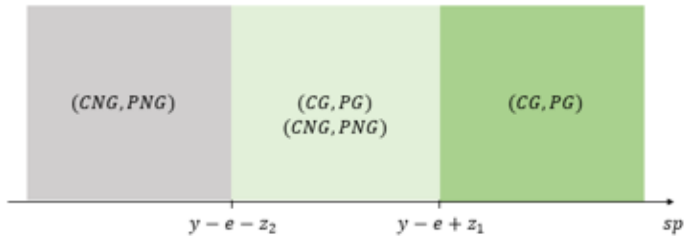
# RESULTS

## MODEL B2 –GOVERNMENT INTERVENTION: FIRM SUBSIDY POLICY (DISCRIMINATORY POLICY)

*Table 7 Representation of the strategic form game with the payoffs of model B2.*

| | | Firm | |
|---|---|---|---|
| | | PG | PNG |
| Consumer | CG | $a, b - y + s_P$ | $a - x_3, b - z_2 - e$ |
| | CNG | $a - x_1, b - y - z_1 + s_P$ | $a - x_2, b - e$ |

- Solving the game in pure strategies:
  - No dominant strategy for the consumer;
  - If $s_P > y - e + z_1$ (and thus $s_P > y - e - z_2$), the firm has a dominant strategy – *Produce Green* – and the Nash equilibrium is $(CG, PG)$;
  - If $s_P < y - e - z_2$, the firm has as dominant strategy *Produce Non-Green* and the Nash equilibrium is $(CNG, PNG)$.
  - When $y - e - z_2 < s_P < y - e + z_1$ there is no dominant strategy for the firm, but there are two Nash equilibria, $(CG, PG)$ and $(CNG, PNG)$.



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## MODEL B2 –GOVERNMENT INTERVENTION: FIRM SUBSIDY POLICY (DISCRIMINATORY POLICY)

*Table 7 Representation of the strategic form game with the payoffs of model B2.*

| | | Firm | |
|---|---|---|---|
| | | PG | PNG |
| Consumer | CG | $a, b-y+s_p$ | $a-x_3, b-z_2-e$ |
| | CNG | $a-x_1, b-y-z_1+s_p$ | $a-x_2, b-e$ |

- Solving the game in mixed strategies:
  - Consumers adopt a green attitude with probability $\mathrm{p} = \frac{y+z_1-e-s_p}{z_1+z_2}$ and firms produce green with probability $\mathrm{q} = \frac{x_3-x_2}{x_3-x_2+x_1}$;
  - Notice that $q$ is not affected by the discriminatory policy, $p$ is.
  - Under this policy intervention, the value of $p$ is lower than in the scenario with no policy $\left(\frac{y+z_1-e-s_p}{z_1+z_2} < \frac{y+z_1}{z_1+z_2}\right)$. Measures that act to reduce the opportunity cost of investing in low-carbon strategies contribute to diminish probability $p$.

# RESULTS

## MODEL C – ACQUISITION AS AN INNOVATION STRATEGY

*Table 8 Model C: Representation of the strategic form game with the payoffs of model C.*

| | | Firm | | |
|---|---|---|---|---|
| | | PG | PNG | BG |
| Consumer | CG | $a, b-y$ | $a-x_3, b-z_2$ | $a-x_4, b-k$ |
| | CNG | $a-x_1, b-y-z_1$ | $a-x_2, b$ | $a-x_1-x_4, b-z_1-k$ |

- We explore the possibility of the firm acquiring an innovative startup as a means of developing the green product, assuming there is no government intervention;
- The difference between this model and the previous models is the firm's extra strategy (*Buy Green*) and the parameters $x_4$, the utility loss that results from a more concentrated market (less options available for the consumer), and $k$, the acquisition cost;
- If the acquisition goes forward, the firm has to pay the acquisition cost $k$ but saves the innovation cost $y$.

# RESULTS

## MODEL C – ACQUISITION AS AN INNOVATION STRATEGY

*Table 8 Model C: Representation of the strategic form game with the payoffs of model C.*

| | | Firm | | |
|---|---|---|---|---|
| | | PG | PNG | BG |
| Consumer | CG | $a, b-y$ | $a-x_3, b-z_2$ | $a-x_4, b-k$ |
| | CNG | $a-x_1, b-y-z_1$ | $a-x_2, b$ | $a-x_1-x_4, b-z_1-k$ |

- Regarding pure strategies:
  - $k$ can be higher or lower than $z_2$ (the revenue lost when selling a non-green product to a consumer with a green attitude). Depending on the parameters' combinations, we can have a single Nash equilibrium (non-green) or two (one green and the other non-green);
  - N.E. $(CG, BG)$ is only obtainable if $k < z_2$. The undesirable N.E. $(CNG, PNG)$ is always an equilibrium regardless of the relationship between $k$ and $z_2$.

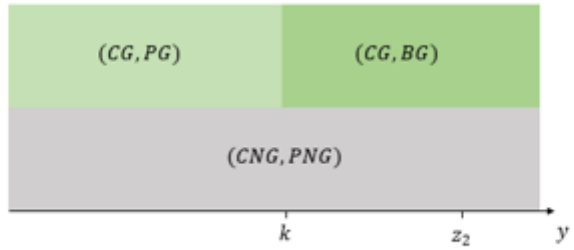


*Figure 2 - Nash equilibria in pure strategies as a function of $y$, when $k < z_2$.*

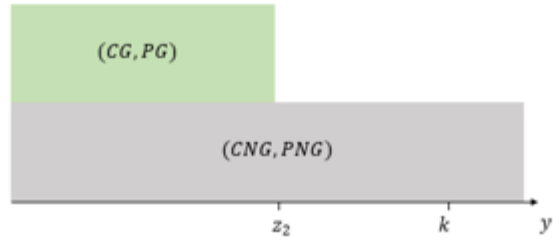


*Figure 3 - Nash equilibria in pure strategies as a function of $y$, when $k > z_2$.*

# RESULTS

## MODEL C – ACQUISITION AS AN INNOVATION STRATEGY

*Table 8 Model C: Representation of the strategic form game with the payoffs of model C.*

| | | Firm | | |
|---|---|---|---|---|
| | | PG | PNG | BG |
| Consumer | CG | $a, b-y$ | $a-x_3, b-z_2$ | $a-x_4, b-k$ |
| | CNG | $a-x_1, b-y-z_1$ | $a-x_2, b$ | $a-x_1-x_4, b-z_1-k$ |

- Solving the game in mixed strategies:
  - The probability of the firm offering a green alternative is $q + r = \frac{x_3 - x_2}{x_1 + x_3 - x_2}$, where $q$ is the probability of the firm investing in innovation in-house and $r$ the probability of the firm choosing an acquisition;
  - If $k > z_2$ or if $y < k < z_2$ the firm always prefers to invest in the innovation in-house. The probability of the consumer choosing a green product is $p = \frac{y + z_1}{z_1 + z_2}$ (like in model A);
  - If $k < z_2$ and $k < y$ the firm always chooses acquisition. The probability of the consumer choosing a green product is $s = \frac{k + z_1}{z_1 + z_2}$.

# RESULTS

## SEQUENTIAL GAMES – FIRM DECIDES FIRST

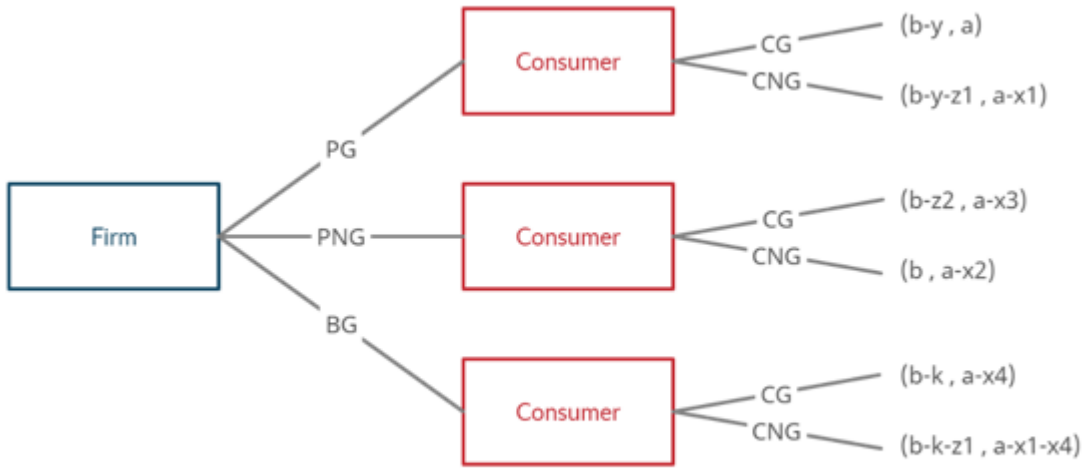


*Figure 4 - Representation of sequential game in which the firm decides first.*

- The subgame perfect Nash equilibrium is $(CNG, PNG)$.

# RESULTS

## SEQUENTIAL GAMES – CONSUMER DECIDES FIRST

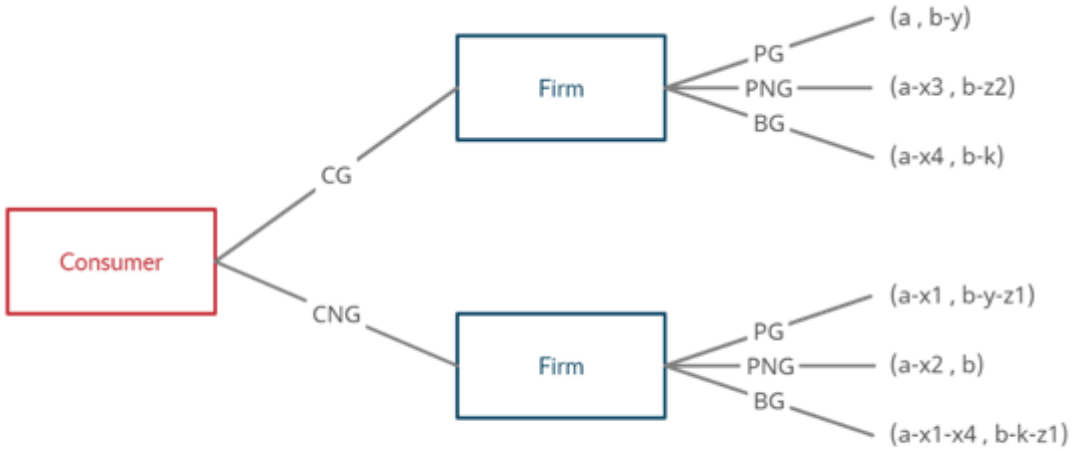


*Figure 4 - Representation of sequential game in which the consumer decides first.*

A sequential game in which the players could make a second round of decisions was also solved but the Subgame Perfect Nash Equilibrium possibilities are the same as in the sequential game with just one round.

- If the consumer chooses *Consume Non-Green* the subgame perfect Nash equilibrium will inevitably be $(CNG, PNG)$.
- If the consumer chooses *Consume Green* several subgame perfect Nash equilibria arise from the different possible relationships between parameters $y$, $k$ and $z_2$:

*Table 9 - Subgame perfect Nash equilibria when the consumer decides first.*

| Min{$z_2$,y,k} | Subgame Perf. NE |
|---|---|
| $z_2$ | $(CNG, PNG)$ |
| $y$ | $(CG, PG)$ |
| $k$ | $(CG, BG)$ |

# CONCLUSIONS

- The best outcome (in terms of welfare) for the two sides of the market is when both parties, consumers and producers, are aligned towards the same goal;

- An outcome in which both firms and consumers prefer to have a green attitude is obtainable but, either there is government intervention or consumers take a leadership position and dictate the rules of the market;

- Under firm discriminatory policy the proportion of consumers with a green attitude required for the firm to opt to innovate in low-carbon strategies is reduced (the firm is more likely to innovate and offer green products);

- A green outcome via acquisition is only obtainable if the acquisition cost is lower than the revenue lost due to the mismatch between demand and supply.

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