INNOVATION DECISIONS FOR GREEN PRODUCTS: THE ROLE OF REGULATORY INCENTIVES AND ACQUISITIONS IN A CONSUMER-FIRM GAME

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Abstract

Developing green products is emerging as a strategy for reaching environmentally conscious consumers and capture a (green) price premium. Yet, without government intervention many firms are hesitant to conduct low-carbon innovation. This paper applies a management science game theory approach to analyze low-carbon innovation decision-making processes by firms, together with green consumption choices by consumers for which product "greenness" is a vertical attribute. We test the impacts that government intervention may have on innovation through consumer subsidization and discriminatory policies applied to firms. The effects of obtaining a desirable green innovation via acquisition (technology transfer), instead of investing in R&D, are also examined. Some managerial implications on the decision-makers' variables and on the order of play are discussed. Low innovation costs and synchronized decisions between firms and consumers arise as crucial to drive society towards a sustainable path.

Keywords: Game theory; Green technology innovation; Discriminatory policy; Acquisitions.

1. Introduction

The need to address climate change is a major global concern and exploring and implementing a new model for a low-carbon sustainable economy is inescapable [26, 31, 19]. Issues such as climate change, oil dependence, clean technology, and related challenges, occupy increasing amounts of managerial time. Rapidly evolving preferences, regulations, and technologies benefit flexibility over myopic strategies. Thus, new market opportunities are created from green stakeholders, especially consumers [14, 20].

In fact, consumers are increasingly aware of the impact that their consumption choices have and are paying more attention to sustainability[1]. As a result, supplying green products is emerging as a firm strategy for reaching these environmentally conscious consumers [15, 11, 13]. Many firms engage in strategic corporate social responsibility to capture environmental or socially responsible consumers. The objective is to maximize their profits by privately providing a public good as part of their business or marketing strategy (e.g., cause-related marketing or eco-labeling) [13]. Corporate social responsibility is by itself a competition tool. Accordingly, firms in more competitive markets may engage more in corporate social responsibility, to gain a competitive advantage [1].

Firms also gain and sustain competitive advantage by developing long-term corporate technology strategies for acquiring technological resources [12]. Yet, many firms are hesitant to conduct low-carbon innovation due to the requirement of high initial investment, the uncertainty involved in the whole process, and the long cycle of return. The costs and risk of developing new low-carbon products or technologies are relatively high. Without low-carbon policies firms may lack incentives to overcome their self-interest and invest in innovation. Furthermore, relying only on the market is not enough to allow social investment to reach optimal levels, given the multiple externalities of green technological innovation. Therefore, government incentives and environmental and market regulations are needed to address market failures and barriers [8, 14, 10, 30, 11]. The government must have a supervisor role and be a regulator of the strategy selection of firms, in order to promote

[1] A global survey by Accenture shows that 83 per cent of consumers consider important or extremely important for firms to offer products that can be reused or recycled. Moreover, around 72 per cent of respondents claim they are purchasing more environmentally friendly products than in the previous five years [2]. In addition, another survey shows that the pandemic might cause long-term changes in consumer behaviors. Consumers are now considering more seriously the health and environmental impacts of their purchasing choices and will likely continue to do so [3].

and guide firms to a low-carbon technological innovation path, using its ability to provide firms with optimal incentives to innovate [8, 27, 16].

Environmental policies used to support firms investing in clean technological innovation can be divided into direct and indirect policy instruments. Direct approaches include subsidies, rebates, tax deductions, and general energy price reforms. Indirect measures include eco-friendly labeling, energy education, or consumer loyalty and awareness enhancement [27, 30, 31, 9].

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. For instance, [5] show that the abatement increases with a policy that rewards clean producers and falls with a policy that punishes the non-clean producers. [4] also show that any tax applied to environmentally hazardous products reduces the abatement level of firms, while subsidizing firms increases the overall clean-up level, as well as increasing the total number of consumers served. [21] show that specific policy instruments such as a minimum quality standard or the use of greener technologies have the expected positive effects on environmental surplus, while incentivizing green consumerism leads to a decrease of the environmental surplus because, by offering a green differentiated product, firms increase their market power and raise prices, leading consumers to buy more of the non-green alternatives. [19] show that green subsidies encourage developing countries to reduce transboundary pollution, whereas without regulation countries have a myopic view and do not reduce emissions.

Furthermore, [9] show that taxing the sales of non-green products (so that the social cost is fully incorporated in the price consumers pay) results in a suboptimal provision of product greenness. In addition, [18] show that subsidies and low taxes can boost competition, making the less green firm, as well as his rival, more aggressive in their pricing strategy. On the contrary, raising taxes makes the less green firm soften his pricing strategy, reducing the intensity of price rivalry between firms. Thus, as suggest by [24], environmental policies must take into consideration not only the effects they may have on the products' green features but also their implications on the consumers' allocation between the firms.

Even tough carrying out low-carbon technological innovation demands a significant investment from firms, which may or may not receive incentives from the government, innovation can also be obtained via acquiring a firm that already owns the technology desired (thus, complementing the firm's assets) or has relevant know-how/production capabilities. Given that technology managers are usually under pressure to enhance productivity and investment returns, the use of external connections and resources is a common practice to efficiently obtain technological capabilities [12].

In fact, technology transfer is often achieved by means of firm acquisition and the prospects of these acquisitions may offer startups a strong innovation incentive (entry for buyout). Besides, in industries where products and markets are well defined, preemptive acquisitions are more common [6, 25, 28, 12]. Although the body of research concerning green product diversification decisions and interactions between rival firms, consumers and governments is relatively rich, existing studies have hardly touched the subject of acquisitions as a way for incumbent firms to acquire innovative and otherwise costly low-carbon solutions. To our knowledge, this paper is the first attempt to model technology transfer and acquisitions as a path to acquire low-carbon technologies alongside with government regulation.

This paper builds upon a branch of literature that uses game theory models, namely, duopolistic vertical differentiation, in which greenness is the vertical attribute, to explore green innovation incentives driven by market forces and incentives (for instance, 21, 22, 7, 9, 13, 29, 5, 24]. 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. The models consist of consumer-firm games and the Nash equilibria in both pure and mixed strategies are derived and discussed. This approach is similar to [23], although applied to a different context. Given the characteristics of the models in our paper, they can be generically applied to any technology-dependent sector, and for any products for which green and non-green versions of a product coexist. Examples include retail electricity, vehicles, food, textiles, detergents, paints, among others.

These questions are important not only from a theoretical perspective but have also significant implications. The game model formulation and results can aid managers, especially technology managers, to recognize the numerous factors and costs that should be considered in the decision of developing a low-carbon innovation in-house or acquiring technology capabilities externally. Moreover, the model allows managers to assess the impact that government incentives, namely firm discriminatory policy, can have on their low-carbon innovation decisions and strategies.

The paper is organized as follows. Section 2 presents the methodology and the characteristics of the games. Section 3 shows the equilibria for different game approaches. Section 4 provides managerial implications and concludes.

2. Decision-making game theory models

Game theory uses mathematical models to foretell the behavior of different agents in situations of cooperation and conflict. The focus is on the interactions amongst players, formulating hypothesis for their behaviors and predicting the end results. Besides many other applications, game theory is commonly applied to environmental policies and in the field of sustainable development [10, 27, 30, 14, 19, 31].

In this paper the game players are the consumer and the firm, both rational players aiming at maximizing their payoffs. They are representative of consumers and producers in the society. The consumer has two strategies available: *Consume Green* (CG) and *Consume Non-Green* (CNG). Since we assume that product "greenness" is a vertical attribute, similar to intrinsic quality, no consumer finds "greenness" undesirable *per se* and so the highest utility will be associated with the consumer that decided to purchase green and has indeed a green product available. Moreover, choosing to consume green implies a willingness to pay for a green premium. The firm also has two strategies available: *Produce Green* (PG) and *Produce Non-Green* (PNG). We assume that the firm is not green or does not have a green product available and so in order to produce green it will have to invest in technological innovation (for instance R&D).

Table 1 depicts a matrix of the game in strategic form. Payoffs are represented by *C* if they refer to the consumer, and *F* if they refer to the firm. The first subscript of the payoffs represents the consumer's decision and the second one the firm's decision. The numbers are assigned regarding the actions taken, thus 1 means green and 2 means non-green. This game representation assumes that decisions are taken simultaneously, or without observing the other player's decision. This representation may be suitable when the consumer decides to follow a green lifestyle or acquire an environmental-friendly product or service before searching for green alternatives, and the firm decides to invest in low-carbon production strategies without having all the information about the consumers' attitude. One example concerns the energy market and the stability of the energy system. Energy generators supply power at the same time that customers demand power. Indeed, an energy balance, a very important condition for energy systems stability, is achieved when power generation is equal to power demand. This is a simultaneous interaction in which consumers do not know the source of the power (green energy or not) that will be supplied to them and the producers (generators) do not know the preferences of the consumers. Table 2 depicts the parameters within each payoff, for which $a, b, x_1, x_2, x_3, y, z_1, z_2 > 0$.

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	$C_{11} = a$
	$C_{12} = a - x_3$
	$C_{21} = a - x_1$
	$C_{22} = a - x_2$
Firm	$F_{11} = b - y$
	$F_{12} = b - z_2$
	$F_{21} = b - y - z_1$
	$F_{22} = b$

When the consumer decides to buy green and the firm offers a green product the consumer's payoff is maximum (a).When there is a mismatch between the consumer's decision and the product available, the consumer has less utility (represented by the loss x_1 or x_3). In case the consumer opts for a non-green purchase and there is in fact a non-green product available (C_{22}), there is still a loss , x_2, because the vertical differentiation assumption implies that "greenness" is a vertical attribute, and so it is never undesirable. For this reason, the consumer that decided to follow a non-green strategy is better off having a green product than having a non-green product ($x_1 < x_2$). Indeed $x_1 < x_2 < x_3$, meaning that the worst case-scenario for the consumer is to choose to consume green but being compelled to buy non-green (C_{12}). This in turn implies that $C_{11} > C_{21} > C_{22} > C_{12}$. Moreover, we assume that x_1 and x_2 are lower than a, so that the non-green consumer always derives a positive utility from consumption, but x_3 may be higher or lower than a. Notice that if $x_3 > a$, the consumer would have a negative utility from consuming the non-green good, hence she/he would not purchase it, making C_{12} and F_{12} equal to 0 (no payoffs are generated, because no trade takes place) [2]. In what follows we assume that $x_3 < a$.

The payoff obtained by the firm when it sells a non-green product to non-green consumers is denoted by b. If the firm decides to offer green products (recall that the firm is a non-green firm or does not have a green product available) it will have to invest in low-carbon innovation, which costs y. As noted by [21], producing goods with higher quality often requires more expensive inputs and better management practices, besides additional overhead expenditures, such as R&D. Moreover, this cost y includes, *inter alia*, the risk of developing technologies that do not reach the expected outcome. Every time there is a mismatch between the product offered and the consumer's decision, the company loses revenue, with $z_1 < z_2$ since the biggest loss for the firm occurs when it sells a non-green product to a consumer that decided to have a green behavior, because this pair of choices corresponds to the consumer's lowest utility. The highest payoff for the firm occurs when the consumer decides non-green and the firm produces non-green (F_{22}), because there is no mismatch between demand and supply and no innovation costs. The order of F_{12} and F_{11} depends on the values that z_2 and y take, that is, the comparison between lost revenue and innovation cost, with $F_{12} > F_{11}$ if and only if $y > z_2$. In turn, the order of F_{12} and F_{21} depends on the relationship between y, z_2 and z_1. We are able to establish that $F_{22} > F_{11} > F_{21} > F_{12}$ for $0 < y < z_2 - z_1$, $F_{22} > F_{11} > F_{12} > F_{21}$ for $z_2 - z_1 < y < z_2$, and $F_{22} > F_{12} > F_{11} > F_{21}$ for $y > z_2$. Table 3 summarizes the relationships between the payoffs.

[2] When $x_3 > a$ (but still $x_2 < a$) the consumer is radical green, i.e., prefers not buying the good at all than to buy a non-green version product.

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
$F_{22} > F_{11} > F_{21} > F_{12}$; $0 < y < z_2 - z_1$
$F_{22} > F_{11} > F_{12} > F_{21}$; $z_2 - z_1 < y < z_2$
$F_{22} > F_{12} > F_{11} > F_{21}$; $y > z_2$

The next subsections will present 5 different scenarios. First, a model with no government intervention, so the players (consumer and firm) do not have any type of external incentive affecting their decisions. Then, two models with government intervention: one in which the consumer that chooses green receives a subsidy, other in which the government applies discriminatory policy, benefiting the firm when it produces green (via subsidy) and punishing the firm when it does not produce green (e.g., via tax or carbon price). The next scenario deals with the hypothesis of the firm acquiring a startup in order to obtain the desirable green innovation that complements its assets, instead of investing in R&D and develop the innovation in-house. Finally, the last scenario admits that one side of the market observes the characteristics (green attitude/green production) of the other side before making its own decision (sequential decision making).

3. Results

In this section, equilibria in both pure and mixed strategies will be provided for models with a simultaneous configuration, and the subgame perfect Nash equilibria will be provided when dealing with sequential models.

3.1. Model A: no government intervention

In this subsection a model without government intervention is presented. This model will serve as a baseline for the next models, in which measures to incentivize green production and consumption will be added, as well as the possibility of obtaining a green innovation via acquisition. Table 4 shows the payoff matrix of model A.

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, we observe that

(i) The consumer does not have a dominant strategy. She/he chooses to consume green if she/he expects the firm to offer a green product and non-green if she/he expects the firm not to offer a non-green product;

(ii) If $y > z_2$, the firm's dominant strategy is to *Produce Non-Green*. Thus, the Nash equilibrium is (CNG, PNG);

(iii) If $y < z_2$, the firm does not have a dominant strategy and there are two Nash equilibria: (CG, PG) and (CNG, PNG).

In any case ($y > z_2$ or $y < z_2$) the market equilibrium presents no mismatch between the demand and the supply side. The Nash equilibrium thus 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.

When players randomize decisions instead of playing a given strategy with certainty, i.e., when they use mixed strategies, it can be seen that the equilibrium is given by (p, q) with $p = \frac{y+z_1}{z_1+z_2}$, where p is the probability of the consumer choosing a green product, and $q = \frac{x_3-x_2}{x_3-x_2+x_1}$, where q is the probability of the firm investing in producing a green alternative[3].

It is immediate to observe that $0 < q < 1$, which is compatible with the consumer not having a dominant strategy. It is also clear that $p > 0$; however, $p < 1$ if and only if $y < z_2$, because, as seen above, if $y > z_2$ the firm has a dominant strategy, so never randomizes.

In sum, if $y > z_2$ there is only one Nash equilibrium: (CNG, PNG). If $y < z_2$ there are two Nash equilibria in pure strategies, (CG, PG) and (CNG, PNG), plus a Nash equilibrium in mixed strategies in which consumers adopt a green attitude with probability $\frac{y+z_1}{z_1+z_2}$ and firms produce green with probability $\frac{x_3-x_2}{x_3-x_2+x_1}$. Note that the likelihood of consumers adopting a green attitude is increasing in y and in z_1 and decreasing in z_2. The intuition is the following: if the innovation cost y increases or if the revenue reduction z_1 from selling green to a non-green consumer expands (which is part of the expected payoff when producing green), the firm needs a higher likelihood p of facing green consumers to keep the indifference between producing green and non-green; if the revenue reduction z_2 from selling non-green to a green consumer contracts (which is part of the expected payoff when producing non-green), the firm needs a higher likelihood p of facing green consumers to keep the indifference between producing green and non-green; if the revenue reduction z_2 from selling non-green to a green consumer contracts (which is part of the expected payoff when producing non-green), the firm needs a higher likelihood p of facing green consumers to keep the indifference between producing green and non-green. In turn, the likelihood of firms producing green is increasing in x_3 and decreasing in x_1 and x_2: if the utility loss a green consumer faces when buying non-green (x_3) increases, the consumer needs a higher likelihood q of facing green products to keep the indifference between choosing green and non-green; if the utility reduction a non-green consumer faces when buying green (mismatch) or non-green (lower quality) products decreases, the consumer needs a higher likelihood q of facing green products to keep the indifference between choosing green and non-green alternatives. See Figure 1 for a representation of all possible equilibria.

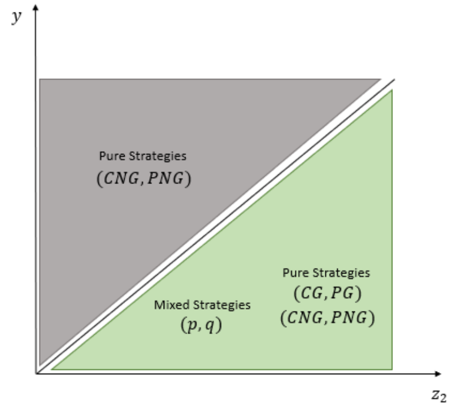

Figure 1 Nash equilibria of Model A depending on revenue lost when selling non-green to green consumers (z_2) and on the opportunity cost of producing green (y).

[3] In a mixed strategies Nash equilibrium, players do not play a given strategy with certainty, rather they randomize between different alternatives with equilibrium probabilities. In our model, the firm is indifferent between producing green and producing non-green when the expected value is equal for both options. These expected values depend on the probabilities p and $(1-p)$ attached to the two possible behaviors of the consumer. Hence, the indifference condition is $p(b-y) + (1-p)(b-y-z_1) = p(b-z_2) + (1-p).b$, which yields the equilibrium p above. Likewise, the consumer is indifferent between adopting a green attitude and adopting a non-green attitude when the randomization of the firm is such that $q.a + (1-q)(a-x_3) = q(a-x_1) + (1-q)(a-x_2)$, which yields the equilibrium q above.

To sum up, society cannot transition to a green path if the cost of investing in low-carbon innovation is higher than the revenue lost when selling a non-green product: under these circumstances, there is only one Nash equilibrium which is (CNG, PNG). Only when $y < z_2$ the society might be able to move towards a green path (and even there it is not guaranteed, given that (CNG, PNG) is still a Nash equilibrium.

Table 5 exhibits the sum of the payoffs for all possible pairs of strategies. It is noteworthy that since $x_2 < x_3 + z_2$, total welfare associated with (CNG, PNG) is higher than total welfare associated with (CG, PNG). This means that even though low-carbon technological innovation provides multiple positive externalities, as long as firms have a non-green behavior it is preferable from a private point of view that consumers also have a non-green attitude. This puts in evidence the inconsistency between private and social objectives in the presence of externalities and goes in line with the hypothesis of [30], in which the discrepancy between costs and benefits arising from technological innovation may lead to Gresham's law dilemmas, a situation in which a bad product drives a good product out of the market.

Table 5 Sum of payoffs.

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

Moreover, given that, on the one side total welfare associated with (CNG, PNG) is higher than total welfare associated with (CG, PNG) and, on the other side, total welfare associated with (CG, PG) is higher than total welfare associated with (CNG, PG), one can conclude that the best outcome for the two sides of the market as a whole is when both parties, consumers and producers, are aligned towards the same goal. Yet, one should also notice that total welfare when both players are green is higher than total welfare when both players are non-green if and only if $y < x_2$. Hence, having green production and green consumption is the best outcome only when the innovation cost of producing green is lower than the quality loss for non-green consumers of consuming non-green[4].

3.2. Models B: government intervention

In this section government intervention is added to the model developed in 3.1. and the impact on the equilibria of the consumer-firm game is analyzed. We consider, first, a model with a subsidy for the consumption of green goods, and then a model with discriminatory policy applied to the firm.

3.2.1. Model B1: Consumer subsidy policy

In this model the government applies a subsidy to green consumption. Therefore, now the payoffs of the consumer also include the subsidy parameter (s_C). The relationship between all the other parameters, besides s_C, is the same as before. Table 6 presents the payoff matrix of model B1, for which $a, b, x_1, x_2, x_3, y, z_1, z_2, s_C > 0$.

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	$a + s_C - x_1 , b - y - z_1$	$a - x_2 , b$

[4] Notice that in this paper total welfare stands for social welfare, not environmental welfare. As noted by [21], offering green products increases social welfare but might decrease environmental welfare. This might happen because, even though consumers have more alternatives (which may lead to higher social welfare), when firms offer a green differentiated product their market power may increase, as well as the price of the green product, leading consumers to buy more of the non-green alternative (and thus reducing the environmental welfare).

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

3.2.2. Model B2: Firm subsidy policy

In this model we consider a firm subsidy policy. Following [5], we consider a discriminatory policy which consists of rewarding the better performer with a subsidy and punishing the worst performer with a tax. The parameter s_P represents the benefit the firm receives when innovating and offering a green product ($s_P > 0$) and the parameter e represents the penalty the firm suffers from not offering a green product ($e > 0$). In fact, e does not necessarily need to be a tax, it can be any type of punishment from causing a negative externality. Examples of subsidies include funding opportunities, for instance grants and loans, provided to firms that are willing to adopt eco-friendly technologies (such as those provided by the US Department of Energy) and examples of punishments include carbon prices or mandatory carbon offsets. Once again, the relationship between all the other parameters, besides s_P and e, is the same as in the model with no policy intervention. Table 7 presents the payoff matrix of model B2.

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:

(i) Nothing changes on the side of the consumer since the subsidy targets the firm. Thus, like in the previous models, the consumer does not have a dominant strategy;

(ii) From the side of the firm there are two possible scenarios that depend on the values that s_P, e, y, z_1 take. If $s_P > y - e + z_1$ (and thus $s_P > y - e - z_2$), i.e., if the subsidy received by the firm (s_P) covers the innovation cost (y) minus the punishment (e) from not innovating plus the revenue lost by selling a green product to a non-green consumer (z_1), then the firm has a dominant strategy – *Produce Green* – and the Nash equilibrium is (CG, PG). Similarly, if $s_P < y - e - z_2$, which means that the subsidy received by the firm (s_P) is lower than the innovation cost (y) minus the punishment (e) minus the revenue lost due to the mismatch between green demand and non-green supply (z_2), then 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). See Figure 2 for a representation of the possible Nash equilibria.

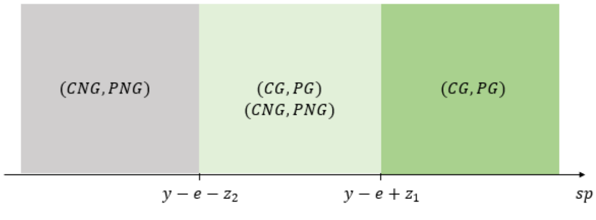

Figure 2 Nash equilibria in pure strategies as a function of s_P.

Contrary to the situation without government intervention, in this model, for sufficiently large values of the subsidy s_P, when the players play pure strategies the result of the game will be with certainty for the firm to produce green and for the consumer to have a green attitude. Indeed, this subsidy should cover the innovation cost and the revenue lost (plus any punishment associated with not producing green).

When players use mixed strategies, the equilibrium is given by: $p = \frac{y+z_1-e-s_p}{z_1+z_2}$, where p is once again the probability of the consumer choosing a green product; and $q = \frac{x_3-x_2}{x_3-x_2+x_1}$, where q is once again the probability of the firm investing in producing a green alternative. Notice that q is not affected by the discriminatory policy, p is. In fact, 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. Thus, under discriminatory policy the proportion of consumers with a green attitude required for the firm to opt to innovate in low-carbon strategies is reduced, which means that, as expected, the firm is more likely to innovate and offer green products.

3.3. Model C: acquisition as an innovation strategy

In this subsection we explore the possibility of the firm acquiring an innovative startup as a means of developing the green product, instead of creating the desirable green innovation in-house, assuming there is no government intervention. Table 8 presents a matrix with this strategic game, in which the firm has three strategies: *Produce Green* (*PG*), *Produce Non-Green* (*PNG*), and *Buy Green* (*BG*). The first subscript of the payoffs represents the consumer's decision and the second one the firm's decision, as before. The numbers are assigned regarding the actions taken, thus 1 means green innovation in-house, 2 means non-green, and 3 means green innovation by means of acquisition. Table 9 shows the payoff matrix of model C, where $a, b, x_1, x_2, x_3, x_4, y, z_1, z_2, k > 0$.

Table 8 Model C: Representation of the strategic form game.

		Firm		
		PG	PNG	BG
Consumer	CG	C_{11}, F_{11}	C_{12}, F_{12}	C_{13}, F_{13}
	CNG	C_{21}, F_{21}	C_{22}, F_{22}	C_{23}, F_{23}

Table 9 Model C: Representation of the strategic form game with the payoffs.

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

The difference between this model and model A concerns parameters x_4 and k. It is assumed that, although apparently the consumer might not be able to distinguish between a green product that is developed in-house and a green product that is developed using a startup's innovation, if the incumbent firm acquires the startup the market goes more concentrated, and the consumer has less options available. In our model, this loss is translated into x_4 in the consumer's payoffs C_{13} and C_{23}. It is assumed that this loss x_4 is lower than the utility loss x_3 of the green consumer that is compelled to buy non-green, due to the mismatch between demand and supply and the inferior quality of the good. Moreover, it may also be assumed that x_4 is lower than the utility loss x_2 of the non-green consumer that buys a non-green product, because this consumer acquires a product with noticeable inferior quality (recall that "greenness" is a vertical attribute like intrinsic quality). Thus, $x_4 < x_2 < x_3$. The relationship between x_4 and x_1 is unclear. The non-green consumer that buys a green product faces a mismatch between its preferences and the product available but ends up with a product with a green attribute (higher quality). Thus, the utility loss caused by this mismatch may be higher or lower than the utility loss caused by the increased market concentration (which is not visible to the consumer in terms of attributes of the product), depending on the perception the non-green consumer has regarding "greenness" as a vertical attribute.

If the acquisition goes forward, the firm has to pay the acquisition cost k but saves the innovation cost y, as it can be seen in F_{13} and F_{23}. Moreover, the cost acquisition k can be higher or lower than the revenue lost when selling a non-green product to a consumer with a green attitude z_2, and the relationship between these two variables determines the different hypothesis for which a green equilibrium may occur in both pure and mixed strategies.

Solving the game in pure strategies, we observe that:

(i) The consumer does not have a dominant strategy. She/he chooses to consume green if she/he expects the firm to offer a green product (either made in-house or via acquisition) and non-green if she/he expects the firm not to offer a green product;

(ii) If the firm expects the consumer to choose the strategy *Consume Green* and $k < z_2$ then: if $k < y < z_2$ or $k < z_2 < y$ the firm chooses *Buy Green* and (CG, BG) is a Nash equilibrium; and if $y < k < z_2$ the firm chooses *Produce Green* and (CG, PG) is a Nash equilibrium;

(iii) If the firm expects the consumer to choose the strategy *Consume Green* and $k > z_2$ then: if $z_2 < y < k$ or $z_2 < k < y$ the firm chooses *Produce Non-Green*; finally, if $y < z_2 < k$ the firm chooses *Produce Green* and (CG, PG) is a Nash equilibrium;

(iv) If the firm expects the consumer to choose the strategy *Consume Non-Green*, the firm always chooses to *Produce Non-Green*, regardless of the relationship between k and z_2, and (CNG, PNG) is a Nash equilibrium.

In sum, depending on the parameters' combinations, we can have a single Nash equilibrium in pure strategies (non-green) or two (one green and the other non-green). Figures 3 and 4 show the different possibilities. Note that the equilibrium (CG, BG) is only obtainable if the acquisition cost k is lower than the revenue lost z_2. Moreover, the undesirable outcome (CNG, PNG) is always an equilibrium regardless of the relationship between k and z_2.

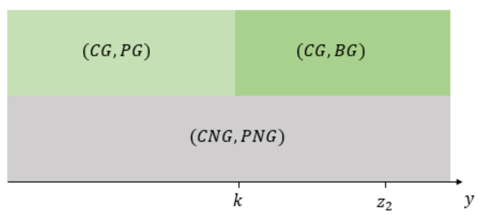

Figure 3 Nash equilibria in pure strategies as a function of y, when $k < z_2$.

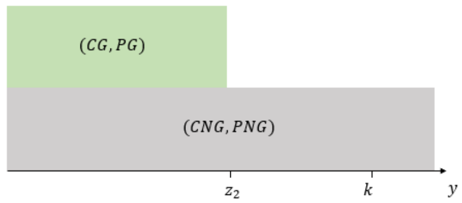

Figure 4 Nash equilibria in pure strategies as a function of y, when $k > z_2$.

Regarding the consumer and recalling that she/he does not have a dominant strategy , she/he can randomize her/his decision regarding a green attitude or not. Indeed, she/he is indifferent between a green and a non-green attitude when 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 producing a green alternative and r the probability of the firm choosing to acquire a startup with the green innovation. It is immediate to observe that $0 < (q + r) < 1$, which is compatible with the consumer not having a dominant strategy.

The joint probability $(q + r)$ increases with x_3 and decreases with x_1 and x_2. This means that, just like in model A, if the utility loss a green consumer faces when buying non-green x_3 increases, the consumer needs a higher likelihood q of facing green products to keep the indifference between choosing green and non-green; if the utility reduction a non-green consumer faces when buying both green and non-green products decreases, the consumer needs a higher likelihood q of facing green products to keep the indifference between choosing green and non-green alternatives. Notice that the utility loss x_4, that arises from the increase in market concentration following an acquisition, does not have any influence on the equilibria.

Regarding the firm's strategies, if $k > z_2$ (the cost of acquisition is higher than the revenue lost by selling a non-green product to a green consumer) or if $y < k < z_2$ (the cost of acquisition is higher than the in-house innovation cost but lower than the revenue lost z_2), then the firm always prefers to invest in the innovation in-house (i.e., acquisition is never an option). Thus, we are in the presence of a model equal to model A. In this situation, the firm only randomizes between producing non-green and producing green in-house, which yields $p = \frac{y + z_1}{z_1 + z_2}$, where p is the probability of the consumer choosing a green product, as seen in 3.1.

However, if $k < z_2$ and $k < y$, i.e., the acquisition cost is lower than the revenue lost and lower than the cost of innovating in-house, then the firm always prefers to acquire an innovative startup instead of investing in innovation. This implies that the firm is left with only two strategies to choose from: *Produce Non-Green* and *Buy Green*. Table 10 displays the matrix of such game.

Table 10 Representation of the strategic form game with the payoffs of model C, assuming k < y.

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

Under this scenario, when using mixed strategies, the firm will be indifferent between choosing to produce non-green and produce green via acquisition if $s = \frac{k + z_1}{z_1 + z_2}$, where s is the probability of the consumer choosing a green product. Now the cost acquisition k affects this probability whereas the cost of investing in innovation no longer affects it. Thus, since the likelihood of consumers adopting a green attitude is increasing in k, if the acquisition cost k decreases the firm needs a lower likelihood s of facing green consumers to keep the indifference between producing green and non-green.

Figure 5 represents all the possible equilibria in mixed strategies as a function of the acquisition cost.

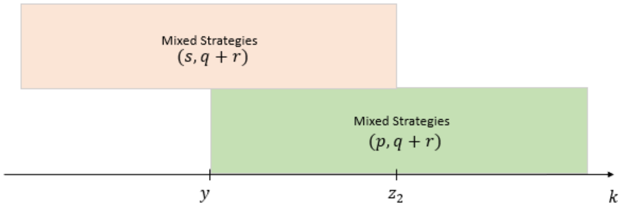

Figure 5 Equilibria in mixed strategies as a function of k.

3.4. Sequential games

Finally, we also analyze if deciding sequentially (instead of simultaneously) affects the results of the last model presented. Let us now admit that one side of the market observes the characteristics of the other side before making its own decision. Hence, we look for subgame perfect Nash equilibria.

Figure 6 represents the sequential game in which the firm decides first, and the consumer decides after knowing the decision of the firm. Under these conditions, as can easily be checked, the subgame perfect Nash equilibrium is (CNG, PNG).

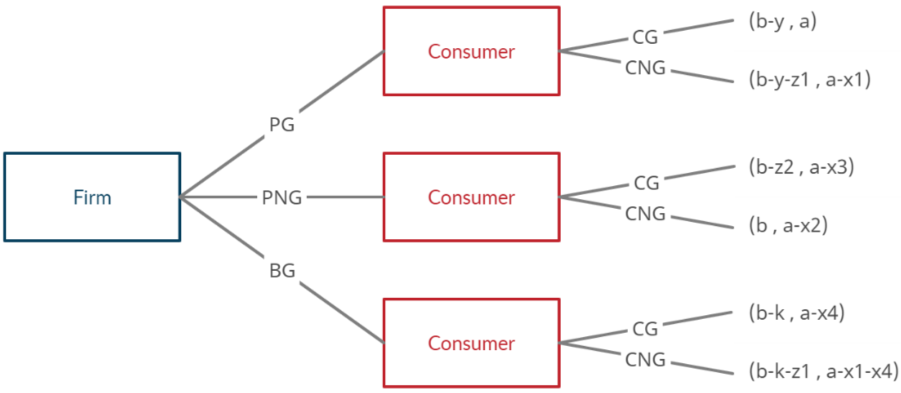

Figure 6 - Representation of sequential game in which the firm decides first.

Figure 7 represents the sequential game in which the consumer decides first, and the firm decides after observing the decision of the consumer. Under these conditions, if the consumer chooses *Consume Non-Green* the subgame perfect Nash equilibrium will inevitably be (CNG, PNG). Yet, if the consumer chooses the strategy *Consume Green* it is possible to reach a green equilibrium, depending on the relationship between y, k and z_2.

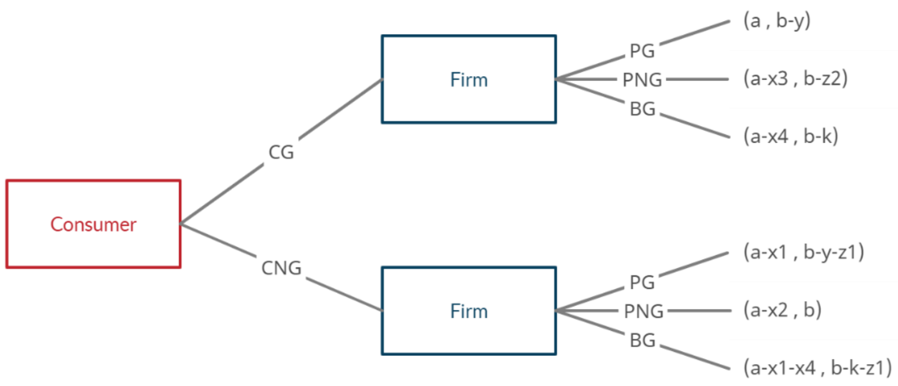

Figure 7 - Representation of sequential game in which the consumer decides first.

Table 11 displays the several subgame perfect Nash equilibria that arise from the different possible relationships between parameters y, k and z_2. Notice that when the revenue lost z_2 is lower than the acquisition cost k or lower than the in-house innovation cost y, the subgame perfect Nash equilibrium will be (CNG, PNG), even though the consumer could have decided to have a green attitude at the beginning[5].

Table 11 - 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)

The main implication arising from these sequential models is that in order to a green equilibrium to be possible consumers must decide first, dictating the rules of the market. Otherwise, if firms decide first society will inexorably end up in a non-green outcome. Moreover, even if the consumer has a leading position, a green result is not a certainty. Indeed, for low values of the revenue lost when selling a non-green product, or high values of the acquisition cost and the in-house innovation cost of producing green, the outcome will still be a non-green society.

4. Managerial insights and conclusions

Consumers' environmental consciousness is an important market-driven factor to achieve environmental sustainability. In fact, the increasing awareness of the need for environmental protection and development of new green products is becoming a market trend. However, firms lack the right incentives to invest in low-carbon

[5] A sequential game in which the players could make a second round of decisions was also solved. Under this game configuration the consumer could choose a non-green attitude in the first round and change to a green attitude in the second round, and *vice versa*. As for the firm decisions, *Produce Non-Green* was always a possible choice, regardless of obtaining the innovation in the previous stage or not (either in-house or by acquisition), as the innovation cost is sunk. If the firm chose green in both rounds, the cost associated with obtaining the low-carbon innovation (either y or k) would only be considered once. Moreover, if an acquisition occurs in the first stage, then *Buy Green* is no longer a possible strategy in the second stage (*i.e.*, an acquisition is a one-time decision). The results of this game are the same as the one-stage game, thus, despite the chance of changing strategies in the second decision stage, the Subgame Perfect Nash Equilibrium possibilities are the same as in the sequential game with just one round, which confirms the robustness of the results presented in Table 11. Regarding total welfare, obtaining green innovation via acquisition [(CG,PG,CG,BG) or (CG,BG,CG,PG)] is always better than remaining non-green (CNG,PNG,CNG,PNG), since $x_4 < x_2$. However, remaining non-green is better than developing the innovation in-house (CG,PG,CG,PG) if $x_2 < \frac{y}{2}$, i.e., if the quality loss for non-green consumers of consuming non-green (vertical differentiation assumption) is sufficiently low as compared with innovation costs.

innovation and to develop long-term corporate low-carbon technology strategies. Without government intervention, there may be a tendency for non-green outcomes to prevail in the society. Given the multiple positive externalities of green technological innovation, relying only on the market does not allow social investment to reach optimal levels.

This paper models decision-making regarding green technology investment and adoption in a firm that may receive incentives from the government to innovate and develop a green product, together with a consumer that considers "greenness" a vertical attribute and is choosing between green and non-green products. A management science game theory approach is used to assess the interactions between the two players. To the best of our knowledge, this paper is the first that models technology transfer and acquisitions as a path to acquire low-carbon technologies alongside with government regulation.

We establish five models to achieve our research objectives. First, a model with no government intervention. Second, two models with government intervention: one in which the consumer that chooses green receives a subsidy, other in which the government applies discriminatory policy, a policy setup in which the intervention rewards the green firm (via subsidy) and punishes the non-green firm (e.g., via tax or carbon price). Then, a model in which the firm may acquire a startup to obtain the desirable green innovation, instead of investing in R&D and develop the innovation in-house. Finally, the last scenario admits that one side of the market observes the characteristics of the other side before making its own decision.

Equilibria in both pure and mixed strategies are provided for all the models with simultaneous decision making, as well as the subgame perfect Nash equilibria for the models with sequential decision making. This model formulation, which can be generically applied to any technology-dependent sector, can assist technology managers identifying the factors and costs associated with the decision of developing a low-carbon innovation either in-house or via acquisition, with and without government incentives.

Several implications arise. First, an outcome in which both firms and consumers prefer to have a green attitude is obtainable but, either there is government intervention that guarantees that the costs associated with the low-carbon innovation are very low and that the utility lost by the consumers when purchasing non-green goods is very high, or consumers must adopt a clear green attitude soon, taking a leadership position and dictating the rules of the market. Indeed, the best outcome for the two sides of the market as a whole is when both parties, consumers and producers, are aligned towards the same goal. Moreover, total welfare when both players are green is higher than total welfare when both players are non-green only if the innovation cost of producing green is lower than the quality loss for non-green consumers of consuming non-green.

Another relevant result is that when the decisions are taken simultaneously between consumers and firms, consumers never have a dominant strategy. Their decisions always depend on what they expect firms to do. However, once they are given the opportunity to decide first, they can drive society towards a green pathway. This has important implications. From the side of the government, policy measures should focus on consumer empowerment. Our results support the need for green education and awareness to encourage consumers to have green aspirations and allowing them to rule the market. On the one side, policy makers should address the opinion and views of consumers regarding the types of products offered by the market, in order to affect their views over non-green products. On the other side, firms that do not adapt to this change in consumers' perceptions and offer green solutions can lose an important advantage and be left behind. Innovation regarding low-carbon technologies can enhance consumers' demand and maintain firms' competitiveness. Accordingly, green marketing arises as an effective tool to convert consumers' awareness into actual purchasing behavior, since, as noted by [15], consumers green attitude is directly related with their knowledge of green products.

When introducing firm discriminatory policy in the model, for sufficiently large subsidy values that cover the cost of innovating, the revenue lost, and any punishment associated with not producing green, if the players play pure strategies the result of the game will be with certainty for the firm to produce green and for the consumer to have a green attitude. If, however, they play mixed strategies, policy intervention should keep both green production subsidies and punishments for firms that create any type of environmental negative externality high, in order to maintain the probability of green behavior that makes consumers and firms indifferent between the two strategies low and hence improve the likelihood of a green outcome. Thus, policy makers may subsidize firms based on the costs of investing in low-carbon technological innovation, reinforcing green production. Nevertheless, the presence of discriminatory policy automatically makes the required probability associated with green consumers' choices lower when comparing with the no regulation situation. Thus, under discriminatory policy the proportion of consumers with a green attitude required for the firm to opt to innovate in low-carbon strategies is reduced, which means that, as expected, the firm is more likely to innovate and offer green products. As for directed government regulation aimed at the consumer, we show that applying a subsidy to the consumption of green goods does not affect the interactions and decisions in the game between consumers and firms.

Regarding the possibility of acquiring a green startup as means to obtain the attractive green innovation, 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. Accordingly, managers that have a potential acquisition in sight should closely track consumer preferences and willingness to pay the green premium, moving forward only when the conditions pay off. Yet, a non-green outcome is always possible, regardless of the relationship between the acquisition cost and the revenue lost.

As noted by [12], governments and industry participants need to make more accurate technology decisions to achieve efficient technology planning and effective technology strategies, therefore contributing to accelerate a low-carbon energy transition.

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