# Not everything is green in the green transition: Theoretical considerations on market structure, prices and competition *

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**Abstract:**

This paper studies how the green transition towards a more sustainable and environmentally friendly economy affects the market structure and the competition between firms. In this context, we propose a two-stage game-theoretical model of competition between firms in prices and green investments. The model delivers several scenarios but two are particularly concerning. One such scenario is called the "dirty" equilibrium, in which firms delay the green transition investments. The other scenario is called the "partial green" equilibrium scenario, in which one firm makes the green transition investments obtaining a leading position, while the other remains producing the "dirty" product. In addition to the associated environmental damages, both scenarios are also problematic because they reduce market competition and the number of firms. In this respect, the "partial green" equilibrium may be even more problematic in the long-run because the green leader may perpetuate its advantage towards some kind of monopoly or market power. Inflation and less competition are particular robust implications of the green transition process that are found in this paper.

**JEL Classification:** H23, L12, D40

**Keywords:** Green transition; Monopoly; Oligopoly; Market power; Green leader.

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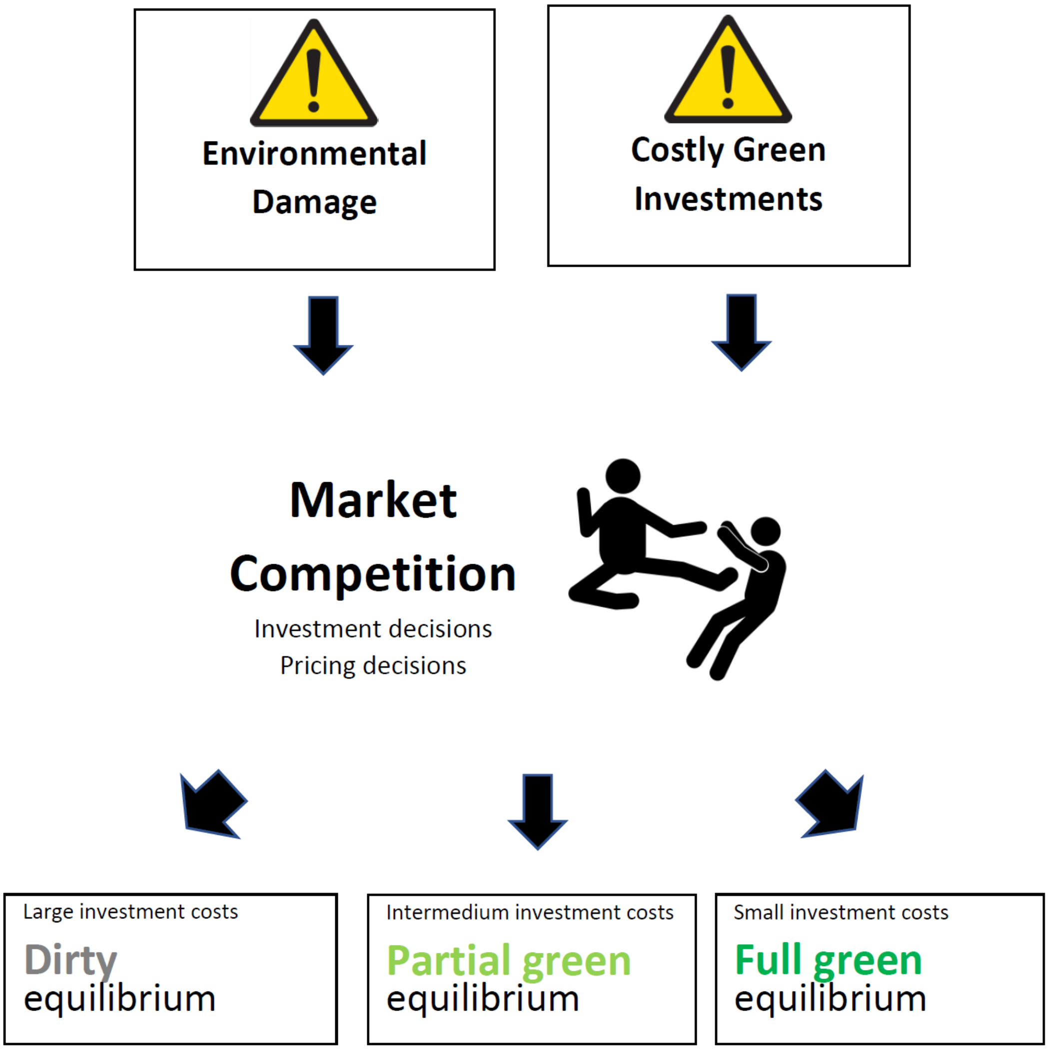
**Graphical abstract/illustration:**



## 1. Introduction

The green transition towards a sustainable and environmentally friendly economy is essential for addressing climate change, resource depletion, and pollution (European Commission, 2020; Rockström et al., 2009). Investment plays a crucial role in driving and supporting the process (OECD, 2021; Stavins, 2020; Van den Bergh, Truffer and Kallis, 2011). In order to reduces greenhouse gas emissions, firms must shift from fossil fuels to renewable energy sources like solar, wind, hydro, and geothermal (Cetindamar, Phaal and Probert, 2016; Stenholm and Visser, 2017). Simultaneously, the supply chain, transportation and logistics must be sustainable, while product design and production must move towards eco-friendly materials, cleaner and energy-efficient technologies, and optimization in the use of materials, waste, energy, and other resources (Bocken et al., 2014; Zeng and Eastin, 2010; Zhai and An, 2020).

All these changes require large investments and large amounts of money to the private firms (Bergman and Hockerts, 2016; Clark, Monk and Yetman, 2017; Correia-da-Silva, Soares and Fernández, 2020). The green transition towards environmentally friendly products and processes will necessarily leave many firms behind either because they have not made the right investment decision in due time or because other firms made it better. Some firms will be able to catch-up and eventually take leading positions, while other firms will be left behind and may end-up losing their market position in a creative destruction process (Grimm and Riedel, 2017; Kivimaa and Kern, 2016; Popp, 2019).

In this context, this paper question how this rapid transition process will affect the markets' structure and competition between firms. What competitive and investment scenarios may emerge during the green transition process and what they will imply in terms of the future market structure and competition. This is an important question because ideally the green transition should not affect competition in any way.

The study of the relationship between green transition and market structure is particularly important. Several papers have studied how the market structure may affects green investments, in particular the interaction with the different environmental policies in terms of efficiency and market failures (Espínola-Arredondo, Munoz-Garcia and Liu, 2019; Martín-Herrán and Rubio, 2018; Phaneuf and Requate, 2017; Schoonbeek and de Vries, 2009). However, little attention has been paid to the implications of the green transition for the market structure as it is done in this paper. This paper investigates this inverse causal relation.

Simultaneously, to the impact in the market structure and competition, green products seem also more expensive to produce, at least in the present moment (Acemoglu et al., 2012; D'Amato and Mancinelli, 2014; Xu et al., 2023). In this context, we are also interested in understanding how the green transition process will impact on prices, welfare and emission levels.

Note that inflation and prices have been in the forefront of the green transition debate (Ambec and Crampes, 2012; Fontaine, Garcia and Minier, 2021; Neuhoff, Keats and Sato 2020), while the reduction of emissions is probably the society most urgent problem and the one that motivates the transition towards green products and production.

Governments also play a crucial role in the green transition through taxation and regulations policies and consumers awareness and education policies that encourage environmentally friendly investments (Bergman and Hockerts, 2016; Chen, Dagestani and Kim, 2023; Schleich and

Walz, 2006; Semmler et al., 2021; Smale and Hartley, 2015; Stavins, 2020). In this context, a series of innovative taxation and incentive mechanisms have been proposed in the literature (Osório and Zhang, 2022a,b; Yi, Wei and Fu, 2021; Zhou et al., 2021). See also Köppl and Schratzenstaller (2022) for a review of some of this literature. In this paper, we are also interested in understanding what governments can do to facilitate the green transition process and avoid potential equilibrium scenarios that can be harmful for consumers, market competition and the environment.

This paper attempts to address these questions. Altogether, the green transition cause enormous changes in the markets and the economy as a whole. In this paper, we try to get a glimpse into some of these changes.

We consider a novel two-stage model with two firms, vertical differentiation and potential first-mover advantages. In this context, we merge the Cournot and the Stackelberg models into a unique vertical differentiation model "a la" Mussa and Rosen (1978). In the first stage, firms take the green investment decisions. In the second stage, firms compete in prices and quantities in the resulting market structure. This type of theoretical approaches is important, in particular in our context, in which the available data about prices, welfare and firms entry/exit decisions is scarce and needs time to build up. This is actually a characteristic of most environmental related research. However, decision and policymakers need to make decision now regarding the future. This paper attempts to provide support in this process.

In this context, we found three main scenarios emerging from the green transition. Scenario (1): The "Dirty" Cournot equilibrium, in which no firm makes green transition investments and both firms keep producing the homogeneous "dirty" product without green concerns. Scenario (2): The "Partial green" Stackelberg equilibrium, in which one firm may decide to make the green transition investment, while the other remains producing the "dirty" product. In this case, the market converges to a vertically differentiated Stackelberg equilibrium in which the green leader produces a vertically differentiated green product. Scenario (3): The "Full green" Cournot equilibrium, in which both firms make the green transition investments, and consequently both firms produce without emissions. In this case, no firm obtains any differentiation or moving advantage over the other as result of the green transition process.

The first two scenarios are particularly concerning in terms of environmental damages, competition and market structure, in particular in the long-run. These two equilibria tend to emerge when the green transition investment costs are high with respect to the industry profitability. In our context, emissions taxation, subsidies to green production or to green transition investments are the three mechanisms that can move the industry or sector away from the "dirty" and the "partial green" equilibria.

We also found that the "full green" equilibria prices are always higher than the "dirty" equilibria prices. This result highlights the idea that green transition necessarily leads to an increase in prices. This inflationary effect is even stronger in the "partial green" equilibrium because of the vertical differentiation effect and the green leader first-mover advantage.

Despite the higher prices found, the utility is highest in the "full green" equilibrium and lowest in the "dirty" equilibrium because of the consumers environmental concerns. This result does not contradict the fact that some consumers, for which the negative price effect is strong than the positive green satisfaction effect, may keep buying cheaper "dirty" goods while freeriding on the other consumers green efforts.

We found that the "dirty" equilibrium is particularly concerning for the environment because the required green investments are delayed as long as it is legally possible to keep producing "dirty". In addition, the lack of investment leaves the door open for the sudden emergence of a green leader or a monopolist, either because green investments are only profitable with one single firm or because an exogenous event my induce a first-mover to perpetuate an advantageous position.

Nonetheless, we argue that the "partial green" transition equilibrium may be even more problematic in the long-run because the green leader obtains a first-moving advantage, while simultaneously vertically differentiate from the competition. The problem emerges if the follower finds difficult to catch-up with the leader or crystalizes/accommodates in the follower position. In this scenario, the green leader may use its advantage to behave pre-emptively in order to establish a perpetual monopoly in the long-run. Consequently, the "partial green" equilibrium is the one that is most likely to reduce the number of firms in the market structure, with long-run implications in terms of prices, competition and consumers welfare.[1]

Another objective of this paper is to look into the future to predict market patterns and propose policy recommendation. In this context, a policy recommendation from this paper is that in order to avoid the emergence of the "dirty" transition equilibrium, it is important that the environmental policy act in the short-run either by subsidizing the green transition investments or by taxing emissions. Nonetheless, we argue that subsidies to green transition investments are the most efficient incentive, as they avoid the randomness of the green transition process and the emergence of a "partial green" or "dirty" equilibria.

Inflation and a tendency towards more concentrated and less competitive market structures are particular robust finding in this paper. The green transition towards environmentally friendly products and production processes will require large investments that some firms will not be able to do either because they do not have the resources or because they are not profitable in the short-run.

Up to our knowledge, this is the first study that looks at the implications of the green transition process in terms of prices, competition and market structure. For that reason, there is no well stablished literature in this topic. Some studies address or mention related ideas, but to our knowledge this is the first paper that specifically and directly addresses this issue.[2] Therefore, filling a gap in the literature.

The remaining of the paper is organized as follows. Section 2 describes the model and notation. Section 3 presents the main results. Section 4 includes a discussion of the results and their

[1] In our simple two firms' model, we consider the transition from duopoly to monopoly. In different contexts, with less concentrated markets structures, the equilibrium implications just described will be equivalent to a reduction in the number of firms competing. In other words, an increase in the market concentration.

[2] In addition, to other papers mentioned before. For instance, Song and Wang (2018) using data from China found an inverted "U"-shape relationship between market competition and green advantages. Therefore, large green investments may increase concentration. While Zhang, Chen and Shen (2020) argue that the relation between green investments and quality competition depends on whether these investments are substitutes or complements.

implications. The last section draws some of the main conclusions. A sketch of the proofs can be found in Appendix.

## 2. Model and Notation

In this section, we formalize our approach by merging a vertical differentiation model (Mussa and Rosen, 1978), with a no differentiation model in which two firms take green investment decisions and compete in prices for consumers. In this context, we consider a unit mass of consumers who are characterized for their preferences for green products $x$, which are uniformly distributed over the interval $[0,1]$. The higher the value of $x$, the higher the consumer willingness to pay for green products. Firm $i$ produces a good with the quality $s_i \geq 0$. In our setting, quality are the product green characteristics. The higher the value of $s_i$, the greener characteristics the product has. The consumer $x$ utility from buying good $i$ with characteristics $s_i$ at price $p_i$ is given by: $u_i(x) = s_i x - p_i$.

Alternatively, the consumer may prefer to not buy. In this case, the consumer obtains the normalized utility of 0.

In case of **vertical differentiation** there is a consumer $x_1$ that is indifferent between buying the green product $i = 1$ and the dirty product $i = 2$ if $u_1(x) = u_2(x)$, and there is a consumer $x_2$ that is indifferent between buying the dirty product $i = 2$ and not buying any product if $u_2(x) = 0$. Therefore, the demand for the green product is given by:

$$D_1 = 1 - x_1 = 1 - \frac{p_1 - p_2}{s_1 - s_2}. \tag{1}$$

While the demand for the dirty product is given by:

$$D_2 = x_1 - x_2 = \frac{p_1 - p_2}{s_1 - s_2} - \frac{p_2}{s_2}. \tag{2}$$

Note that there is a mass of consumers $x_2 = p_2/s_2$ that do not buy any of the two varieties.

In case of **no differentiation** there a unique price $p_o$ where $o \in \{G, D\}$, and there is a consumer $x_o$ that is indifferent between buying or not buying if $u_o(x) = 0$. Therefore, the aggregate demand for the homogeneous product (green or dirty depending on each case) is given by:

$$D = Q_1 + Q_2 = 1 - x_o = 1 - p_o/s_o. \tag{3}$$

At this stage several notes are in order. First, there is a mass of consumers $x_o = p_o/s_o$ that do not buy the homogeneous good. Second, in the no differentiation case the good is homogeneous because both goods are either green or dirty. In the case that both goods are green the aggregate demand $D = 1 - p_G/s_G$, while in the case that both goods are dirty the aggregate demand $D = 1 - p_D/s_D$. Finally, in the no differentiation case, no firm has a differentiation advantage over the other, consequently firms compete for consumers simultaneously and in quantities. In other words, we are looking for a Cournot equilibrium.

Each firm objective is to maximize its own profit. The game has two stages. In the first stage, firms must decide whether or not to make the green investment. The green investment allows firms to become environmental neutral, either because their production process can produce without emissions or because they products become environmentally friendly. In either case an investment $k_G \geq 0$ is required.

In the second stage, firms must take the price and production decision. While dirty products have a zero marginal cost, green products may be more costly to produce, i.e., they have a positive marginal cost of production $c \geq 0$. However, we also want to consider the possibility that dirty production might be taxed. In other words, each unit of the dirty product pays a tax $t \geq 0$. Therefore, the objective function depends on whether the firms produce a green or a dirty product, i.e.,

$$B_i = (p_i - c)D_i - k_G \;\; \text{or} \;\; B_i = (p_i - t)D_i. \tag{4}$$

Therefore, in the second stage we might have (1) the scenario of two dirty producers competing against each other because none of them made the green investment in the first period, (2) the scenario of two green producers competing against each other because they both made the green investment in the first period, or (3) the scenario of one green producer and one dirty producer compete against each other because one firms made the green investment while the other firm have decided to not do the green investment in the first period.

In this paper, we are also interested in quantifying the environmental damage and aggregate utility associated with each potential equilibrium scenario. In this context, we consider as environmental damage indicator, denoted as $E$, the aggregate sum of units/quantities produced in the economy with the "dirty" technology. On the same time, the aggregate utility is the sum of the utilities of the different types of consumers as follow:

$$U = \int_{M_1} u_1(x)dx + \int_{M_2} u_2(x)dx. \tag{5}$$

Where $M_1$ is the domain of consumers buying from firm 1 and $M_2$ is the domain of consumers buying from firm 2. Note that in the symmetric equilibrium there is no difference between buying from firm 1 or 2 because there is no differentiation.

### 3. Results and Analysis

In this section, we will compute the different green transition equilibria and the conditions that sustain each of them. We will also derive results regarding environmental policy and we will compare prices, environmental damage and aggregate utilities in the different scenarios.

In order to simplify the analysis, consider $s_G = 2$ and $s_D = 1$. Consequently, in order to not run into negative and meaningless values it is convenient consider $c \in [0,2]$ in the "fully green" model, $t \in [0,1]$ in the "dirty" model, and $4 - 3c + 2t \geq 0$ and $4 + 3c - 10t \geq 0$ in the "partially green" model. However, often we will consider that governments apply either no tax $t = 0$ or the Pigouvian tax $t = c$. In such case, the condition $c \in [0,1]$ is enough to keep at least one firm profitable.

### 3.1. Green transition equilibria – derivation ($2^{nd}$ stage)

By backwards induction, we start by computing the second stage Nash equilibrium for the three scenarios that we may encounter.

Scenario (1) – "Dirty" Cournot equilibrium (subscript notation $hD$ which stands for "homogeneous dirty"): The starting point of the analysis is one in which both companies are producing the same homogeneous product without green concerns. This is the dirty state. In this case, we assume there are two companies producing a homogeneous product in a simultaneous price competition Cournot type equilibrium. In this case, both firms obtain the following equilibrium profits:

***Proposition 1:*** *In the homogeneous symmetric "dirty" Cournot equilibrium the prices, environmental damages, aggregate utility and profits are respectively as follow:*

$$p_{hD}^{*} = 1 - \frac{2}{3}(1-t), \;\; E_{hD}^{*} = \frac{2}{3}(1-t), \;\; U_{hD}^{*} = \frac{4}{9}(1-t)^2,$$

$$\text{and} \;\; B_{hD}^{*} = \frac{1}{9}(1-t)^2, \qquad (6)$$

*where the subscript $hD$ stands for homogeneous "dirty" equilibrium.*

Scenario (2) – "*Partial green*" *Stackelberg* equilibrium (subscript notation $vL$ and $vF$ which stands for "vertical leader" and "vertical follower"): Alternatively, one firm may decide to make the green investment, while the other remains producing the dirty output. In this case, the industry converges to a vertically differentiated Stackelberg equilibrium in which the green leader produces a vertically differentiated green output, while the follower produces a dirty output. In the price competition vertically differentiated Stackelberg equilibrium the leader obtains:

***Proposition 2:*** *In the vertically differentiated asymmetric "partial green" Stackelberg equilibrium the green leader and the dirty follower prices, environmental damages, aggregate utility and profits are respectively as follow:*

$$p_{vL}^{*} = \frac{1}{6}(4+3c+2t), \;\; p_{vF}^{*} = \frac{1}{24}(4+3c+14t), \;\; E_{v}^{*} = \frac{1}{12}(4+3c-10t),$$

$$U_{v}^{*} = \frac{1}{576}(272 - 168c + 45c^2 - 208t - 12ct + 116t^2),$$

$$B_{vL}^{*} - k_G = \frac{1}{48}(4-3c+2t)^2 - k_G, \;\; \text{and} \;\; B_{vF}^{*} = \frac{1}{288}(4+3c-10t)^2, \qquad (7)$$

*where the subscript $vL$ stands for vertical leader and $vF$ stands for vertical follower.*

Scenario (3) - *"Full green" Cournot equilibrium* (subscript notation $hG$ which stands for "homogeneous green"): The green investment decision allows firms to produce without emissions and with green concerns. If both firms decide to make the investment decision simultaneously, we are in the fully green state. In this case, no firm obtains a moving advantage over the other. The two firms will be producing the same homogeneous green product in a simultaneous price competition Cournot type equilibrium. In this case, both firms obtain the following equilibrium profits:

***Proposition 3:*** *In the homogeneous symmetric "full green" Cournot equilibrium the prices, environmental damages, aggregate utility and profits are respectively as follow:*

$$p_{hG}^{*} = 2 - \frac{2}{3}(2-c), \;\; E_{hG}^{*} = 0, \;\; U_{hG}^{*} = \frac{2}{9}(2-c)^2,$$

$$\text{and} \;\; B_{hG}^{*} - k_G = \frac{1}{18}(2-c)^2 - k_G. \qquad (8)$$

*where the subscript hG stands for homogeneous "green" equilibrium.*

The proof of the last three propositions follows the discussion that precede them. The rest of the proof can be found in Appendix.

### 3.2. Green transition equilibria – derivation (1st stage)

After having presented the second stage results. Now, we consider the optimal investment decision that each firm makes in the first stage. In order to do it, Table 1 shows the second stage payoffs of both firms in the case they decide or not to make the green transition investment decision. The row player is firm 1. The column player is firm 2.

| | Not Invest | Invest |
|---|---|---|
| Not Invest | $B_{hD}^{*}$ ; $B_{hD}^{*}$<br>*"Dirty" equilibrium* | $B_{vF}^{*}$ ; $B_{vL}^{*} - k_G$<br>*"Partial green" equilibrium* |
| Invest | $B_{vL}^{*} - k_G$ ; $B_{vF}^{*}$<br>*"Partial green" equilibrium* | $B_{hG}^{*} - k_G$ ; $B_{hG}^{*} - k_G$<br>*"Full green" equilibrium* |

Table 1: second stage payoffs matrix for the investment decision.

Therefore, in order to find the subgame perfect equilibrium optimal investment decision of the two stages game, we need to find the Nash equilibrium of the matrix form game in Table 1 in connection with the three different scenarios discussed before. Therefore, we have that:

Scenario (1): Both firms do not invest is the subgame perfect equilibrium if the following payoff inequalities are satisfied:

$$B_{hD}^{*} \geq B_{vL}^{*} - k_G \;\; \text{and} \;\; B_{vF}^{*} \geq B_{hG}^{*} - k_G.$$

Scenario (2): One firms invest but the other firm does not invest is the subgame perfect equilibrium if the following payoff inequalities are satisfied:

$$B_{hD}^{*} \leq B_{vL}^{*} - k_G \;\; \text{and} \;\; B_{vF}^{*} \geq B_{hG}^{*} - k_G.$$

In practice this type of coordination equilibrium is difficult without communication between firms. For that reason, any profile configuration may emerge. In this context, it makes more sense to speak about the third equilibrium in mixed strategies in which firms do not make the green transition investment with probability $p = (B^*_{vL} - B^*_{hG})/(B^*_{vL} - B^*_{hG} + B^*_{vF} - B^*_{hD})$, and will make the green transition investment with the remaining probability. Those probabilities are obtained after solving the equation $p(B^*_{hD}) + (1-p)(B^*_{vL} - k_G) = p(B^*_{vF}) + (1 - p)(B^*_{hG} - k_G)$.

Scenario (3): Both firms invest is the subgame perfect equilibrium if the following payoff inequalities are satisfied:

$$B^*_{hD} \leq B^*_{vL} - k_G \text{ and } B^*_{vF} \leq B^*_{hG} - k_G.$$

This is the most desirable equilibrium because full green transition emerges in the short run.

From the two inequalities that characterize the previous three scenarios we obtain two crucial cutoffs defined as: $\overline{k}_G = B^*_{vL} - B^*_{hD}$ *and* $\underline{k}_G = B^*_{hG} - B^*_{vF}$.

The following proposition formalizes the previous discussion and summarizes our findings, but before that proposition consider the following result.

***Proposition 4:*** *In the short-run, $\overline{k}_G \geq \underline{k}_G$ and we have the following three green transition equilibrium scenarios:*

> *Scenario (1) - "Dirty" equilibrium: For $k_G \geq \overline{k}_G$ there is a subgame perfect Nash equilibrium in which no firm does the green transition investment.*
>
> *Scenario (2) - "Partial green" equilibrium: For $\overline{k}_G \geq k_G \geq \underline{k}_G$ there is a subgame perfect Nash equilibrium in which some firm does the green transition investment and other firm does not, and there is a mixed strategy Nash equilibrium in the investment stage.*
>
> *Scenario (3) – "Full green" equilibrium: For $\underline{k}_G \geq k_G$ there is a subgame perfect Nash equilibrium in which both firms make the green transition investment.*

Therefore, three main scenarios may emerge in the green transition process in the short-run. We will analyse these three scenarios in more detail below. Now, just note that in the "dirty" equilibrium no firm makes the green transition because the green transition investment costs are too high with respect to the industry returns. This is a problematic scenario in which concerns environmental damages and market structure, but it is not the only problematic scenario.

### 3.3. Green transition equilibria - Analysis

Environmental public policy should try to influence market outcomes towards the emergence of "full green" transition equilibrium in the short-run. Such objective can be achieved through policies that are able to push up the cut-off value $\underline{k}_G$. In other words, the idea is to enlarge as much as possible the interval of investment costs in which the "full green" equilibrium emerges. The following result describes how that can be achieved.

Often, in the "dirty" type of equilibria we have emissions taxation, while in the "green" type of equilibria we have higher unit production costs. Therefore, in order to compare those different scenarios, we assume that emissions taxation follows the Pigou recipe $t = c$.[3]

***Proposition 5:*** *The environmental policy can favor the emergence of the "full green" equilibrium in the following three ways:*

*i)* *An increase in the emissions tax increases $\overline{k}_G$ and $\underline{k}_G$.*

*ii)* *A subsidy in the marginal unit cost of green production increases $\overline{k}_G$ and $\underline{k}_G$.*

*iii)* *A subsidy to the green transition investment decreases the value of $k_G$.*

Therefore, tax emissions, and subsidies to green production or green investments are three mechanisms that may move a particular industry away from the "dirty" equilibrium, or even the "partial green" equilibrium, as it is not clear which of these two equilibria are worst in the long-run, for reasons that we discuss in the next section.

In the following result we compare the three equilibria in terms of what they imply in terms of price levels.

**Proposition 6:** *Under the Pigouvian tax scheme, the green prices are highest in the "partial green" equilibrium and lowest in the "full green" equilibrium. Dirty prices are highest in the "dirty" equilibrium and lowest in the "partial green" equilibrium. Green equilibria prices are always higher than "dirty" equilibria prices.*

This result highlights one of the fundamental ideas that green transition necessarily leads to an increase in prices. The inflationary effect is even stronger in the "partial green" equilibrium than in the "full green" equilibrium because the vertical differentiation effect and the green leader first-mover advantage allows important niche and market power effects that push prices even higher. This is one of the reasons why short-run "partial green" type equilibria may present stronger long-run concerns than "dirty" type equilibria. Note also that the inflationary effect is mostly due to differentiation and less competition effects. We are not even considering that the green transition investment costs are passed to the consumers through higher prices. This effect is not present in the model, but we still have an inflationary effect. In the following section, we will develop further this discussion.

The following two results compare the three equilibria in terms of environmental damage and consumers aggregate utility.

The aggregate utility indicator given in expression (5) is particularly interesting because it incorporates the consumers environmental concerns and preferences for green products. While

[3] Environmental pollution generates negative externalities costs that are borne by society rather than by the producers of those externalities. The Pigouvian tax aims to force the producer of "dirty" goods or services that create adverse side effects for society to internalize those externalities.

on the other hand the environmental damage is captured by the environmental damage measure $E$. In terms of analysis, both measures complement each other.

**Proposition 7:** *Under the Pigouvian tax scheme, the environmental damage is highest in the "dirty" equilibrium and lowest in the "full green" equilibrium.*

Not surprisingly, environmental damages follow the "dirty", "partial green" and "full green" decreasing order.

**Proposition 8:** *Under the Pigouvian tax scheme, the consumers aggregate utility is highest in the "full green" equilibrium and lowest in the "dirty" equilibrium.*

Utility is highest in the "full green" equilibrium because in aggregate terms consumers have environmental concerns. Altogether, and in aggregate terms, higher prices do not remove consumers from higher levels of satisfaction in "green" type equilibria. This result does not contradict the fact that some consumers, for which the price effect is strong than the green satisfaction effect, prefer to keep buying cheaper "dirty" goods, while freeriding on the other consumers green efforts. Fundamentally, and epistemologically on its bases, this is one of the main obstacles to the emergence of generalized "full green" type of equilibria across all industries.

## 4. Discussion and Implications

In this section we discuss the obtained short-run equilibria and their long-run implications in terms of market structure and prices in different industries and the economy as a whole. In other words, the obtained equilibria have long-run implications, and we will try to predict and suggest corrective policies when found adequate.

First, the short-run "fully green" equilibrium emerges only in industries in which the green transition investment cost is not very high in comparison with the industry profitability. Those cases are the simplest in which concern environmental policy because firms make the investment decisions by themselves without further stimulus. As we have seen, in this case, environmental damage is minimal and consumers utility is maximal. This is the desired equilibrium. However, there are concerns regarding prices, in particular in industries in which the per unit marginal cost of green production is high.

Nonetheless, in the "fully green" equilibrium we should not expect major implications in terms of market structure because all firms move more or less at the same time and no firm obtains a crucial and definitive advantage or disadvantage during the transition process.

Second, if the green transition investment cost is high in comparison with the industry profitability, it may happen that in the short-run no firm will move ("dirty" equilibrium). This case is particularly concerning because in those industries the green transition investments are delayed as long as it is legally possible. Green investments will be made only when required to meet environmental regulations. All firms will remain producing dirty for long periods of time with devastating effects for the environment.

Moreover, in the “dirty” green transition equilibrium, the long-run implications for the market structure may be large. Since there is no firm with incentives to move, it leaves space for the sudden emergence of a monopoly either because green investments are only profitable with one single firm or because of an exogenous event my induce a first-mover firm to perpetuate an advantageous position.

Note that in our model, we are talking about the transition from a duopoly to a monopoly to keep our analysis as tractable as possible. Under more general circumstances, we will be talking about a reduction in the number of firms competing in that particular industry.

Despite prices remain low, therefore not pressuring in terms of inflation, the “dirty” equilibrium has the most negative impact in terms of consumers welfare. Prices are low but goods are environmentally “dirty”.

Third, in the “partial green” transition equilibrium a green leader firm takes an investment first move. This seemly less complex case emerges for intermediate investment costs. However, this scenario might be the most problematic in the long-run because the green leader obtains a first-moving advantage and vertically differentiate from the follower in a higher value variety. The main problem emerges if the follower finds difficult to catch-up the leader or crystalizes/accommodates in the follower position until it is legally obliged to make a move or eventually shutdown. Simultaneously, the green leader may use its advantage to behave pre-emptively in order to establish a perpetual monopoly in the long-run. Consequently, the “partial green” equilibrium is the one that is most likely to have negative implications in terms of market structure towards less competition with higher prices and lower consumers welfare.

If we take into consideration that “dirty” production is going to be at some point in time forbidden and consequently that the “dirty” equilibrium will be destroyed, the “partial green” equilibrium is the worst equilibrium in which an industry may be trapped on. The reason is that while some firms meet green standards other firms do not. This is a complex scenario regarding policy because it requires asymmetric stimulus that may benefit some firms at expenses of others.

Again, in our simple setup, we model a transition from duopoly to monopoly. In more general contexts, with a larger number of firms, the “partial green” equilibrium implications just described will be equivalent to a reduction in the number of firms competing in the industry.

In comparison with the other scenarios, the prices of the green variety in the “partial green” equilibrium are higher than in the “full green” equilibrium because the green producer can relax competition due to its first moving advantage and its superior green variety. The follower sales will tend to become marginal and the leader position approaches a monopoly position. Consumers’ aggregate utility is also lower than in the “full green” scenario because of the higher prices and the existence of a “dirty” variety.

The environmental damage indicator defined in Section 2 is the total amount of units produced using the “dirty” technology. In the “dirty” equilibrium it corresponds to the aggregate market production, in the “partial green” equilibrium it corresponds to the units produced by the follower, while in the “full green” equilibrium there is no environmental damage. Altogether, in terms of environmental damage, the “dirty” equilibrium is the most harmful to the environment, followed by the “partial green” equilibrium, which reinforce the undesirability of those equilibria and the urgency of action.

In order to avoid the emergence of the “dirty” and the “partial green” transition equilibria, we argue that environmental policy should act in the short-run either by subsidizing green investments and green production, or by taxing emissions. Nonetheless, in our context, we believe that subsidies to the investment are more efficient than tax emissions as they avoid the randomness of the green transition process (e.g., the emergence of “dirty” and “partial green” equilibria, both with negative consequences in terms of market structure and competition, as described before). In this context, subsidies to green investments can move markets directly from the “dirty” equilibrium to the desired “full green” equilibrium in due time. For these reasons they are preferred. This mechanism is faster and more direct. On the other hand, taxes on emissions are not so efficient. While it is true that this policy instrument makes the “dirty” type equilibria more expensive which incentives firms to make green investments in order to leave this equilibrium. However, it does not guarantee that in the long-run the market structure will necessarily converge to the “full green” equilibrium without increasing market concentration and reducing competition, and the transition will occur fast in time. Therefore, subsidies are more effective because they can be linked with to these objectives.

**5. Conclusion**

This paper proposes a novel theoretical model to study the impact of green transition in the market structure, competition, prices, consumers welfare and environmental damages. In this context, this study also aims to predict and understand how the emerging short-run equilibria may feedback into long-run effects in order to guide policymakers implementing corrective policy measures.

We found that in the short-run different industries may converge to different green transition equilibria depending on the magnitude of the investment costs with respect to the industry profitability. In industries in which transition investment costs are relatively low, the transition to the “full green” equilibrium may occur almost immediately and in a very natural way. The problem emerges in industries with high to intermedium green transition investment costs. When the green investment cost is very high, the industry may be trapped into a “dirty” equilibrium in which firms will wait for as long as possible to make the green transition. This is the worst scenario in terms of environmental damages and aggregate utility. It is also a risky scenario in the sense that less competitive market structures may emerge in the long-run as some “dirty” producers may end-up not making the required investments. However, the most concerning scenario in terms of competition emerges for intermediate investment costs, in which a first moving green leader firm vertically differentiate from the competition. The problem is that this advantage may perpetuates into the long-run either through a natural monopoly, in the case the “dirty” follower never makes the green transition investment, or through a pre-emptive monopoly, in case the green leader adapts prices and quantities to restrict the follower incentives to make the necessary investments. Altogether, if we take into consideration that “dirty” production is going to be forbidden at some point in time, this “partial green” equilibrium might be the worst equilibrium in which an industry may be trapped on.

Two robust findings and important messages in this paper are: (1) that green transition to carbon neutrality will necessarily induce an increase in prices, and (2) a tendency towards more concentrated market structures with less competition, which again induces even higher prices. Therefore, green transition will necessarily cause inflation and market concentration. This seems to be the price that has to be paid by the society for better environment and carbon neutrality. Nonetheless, the consumers aggregate utility seems to increase because consumers care about the environment. Therefore, the positive environment effect is stronger than the increase in prices effect.

An implication of the obtained results is that in order to avoid the emergence of the short-run "dirty" or "partial green" equilibria, environmental policy should act either by subsidizing the green transition investments/production or by taxing emissions. Nonetheless, we argue that direct subsidies to green transition investments may be the most fast and efficient mechanism as it avoids the randomness of the green transition process towards undesired equilibria, like the "dirty" and the "partial green" equilibria, which may have severe long-run implications in terms of prices and competition. Taxing emissions may help the transition process, but it is not the most fast and efficient mechanism as it does not avoid the emergence of undesired equilibria.

To conclude, this paper provides an effective and intuitive introduction to the important issues arising from the green transition in terms of prices, competition and market structure. The approach and findings in this paper may open new research avenues for the study of the green transition process, but they are not the last word on the subject. Further research should expand our finds and deliver more granular predictions. In this context, we would like to see the same question in this paper addressed with different approaches and with the resource to empirical methods. We would also like to see alternative policy recommendations to deal with the increase in prices, the reduction in competition and the increase in market concentration induced by the green transition. Not everything seems to be green in the green transition process. Nonetheless, we hope the analysis in this paper can guide researchers and policy-maker better understanding, deciding and predicting potential market outcomes induced by the green transition process.

**Appendix**

This section presents the proof of the main results.

**Proof of Proposition 1:** In the homogeneous symmetric "dirty" Cournot equilibrium each firm simultaneously maximize $B_i$ with respect to quantity, with $k_G = 0$ and demand function given by $Q_1 + Q_2 = 1 - p_D/s_D$, where the subscript $D$ stands for the "dirty" variety. This is the only variety produced in this type of equilibrium. Consequently, we obtain a system of two first order conditions $dB_1/dQ_1 = 0$ and $dB_2/dQ_2 = 0$. Note that the second order condition is trivially satisfied. The solution of the system of first order conditions delivers a pair of symmetric equilibrium quantities. In the next step, replace those quantities in the demand function to obtain the market price $p_{hD}^*$. Similarly, replace the obtained quantitates in the environmental damage, aggregate utility and profit functions to obtain the equilibrium expressions for $E_{hD}^*$, $U_{hD}^*$ and $B_{hD}^*$, respectively.

**Proof of Proposition 2:** By backward induction, in the vertically differentiated asymmetric "partial green" Stackelberg equilibrium the follower firm maximize $B_{vF}$ with respect to the price, with $k_G = 0$ and the demand given by expression (2). Solve the associated first order condition $dB_{vF}/dp_{vF} = 0$ for price and replace it in the leader objective function $B_{vL}$, with $k_G \geq 0$ and demand function given by expression (1), which is then maximized with respect to price $p_{vL}$. The solution of this first order condition delivers the leader green price $p_{vL}^*$, which after replaced in the follower first order condition delivers the follower equilibrium price $p_{vF}^*$. The second order condition is trivially satisfied. Note that there are two vertically different varieties in equilibrium. After replacing the equilibrium prices in the demand function, it returns the firm quantities. Similarly, replace the equilibrium prices in the environmental damage, aggregate utility and profit functions to obtain the equilibrium expressions for $E_v^*$, $U_v^*$ and $B_{vL}^* - k_G$ and $B_{vF}^*$, respectively.

**Proof of Proposition 3:** In the *homogeneous symmetric "full green" Cournot* equilibrium each firm simultaneously maximize $B_i$ with respect to the quantity, with $k_G \geq 0$ and the demand is given by $Q_1 + Q_2 = 1 - p_{hG}/s_{hG}$, where the subscript $G$ stands for the "green" variety, which is the only variety produced in this type of equilibrium. Since the second order condition is trivially satisfied, the solution of the system of the two first order conditions, $dB_1/dQ_1 = 0$ and $dB_2/dQ_2 = 0$, delivers a pair of symmetric equilibrium quantities. After replacing those quantities in the demand function, we obtain the equilibrium market price $p_{hG}^*$. Similarly, replace the equilibrium quantities in the environmental damage, aggregate utility and profit functions to obtain the equilibrium expressions for $E_{hG}^*$, $U_{hG}^*$ and $B_{hG}^* - k_G$, respectively.

**Proof of Proposition 4:** In order to prove this result we first need to show that $\overline{k}_G \geq \underline{k}_G$ always. In this context, note that the cutoffs $\overline{k}_G$ and $\underline{k}_G$ can be written as:

$$\overline{k}_G = \frac{1}{48}(4 - 3c + 2t)^2 - \frac{1}{9}(1 - t)^2 \quad \textit{and} \quad \underline{k}_G = \frac{1}{18}(2 - c)^2 - \frac{1}{288}(4 + 3c - 10t)^2,$$

respectively. Subsequently, define the function of the difference between $\overline{k}_G - \underline{k}_G$, which is continuous and differentiable, and search for its global minimum, which occurs at $c = 2$ and $t = 1$. Since at the minimum point the function takes the value 0, it will imply that $\overline{k}_G \geq \underline{k}_G$ always, i.e., $B_{vL}^* - B_{hD}^* \geq B_{hG}^* - B_{vF}^*$ always. Then, the rest of the proof follows from the discussion that precedes the proposition, and the different Nash equilibrium obtained from matrix form in Table 1. The three different equilibrium scenarios depend on the value of $k_G$ with respect to $\overline{k}_G$ and $\underline{k}_G$ as stated in the proposition.

**Proof of Proposition 5:** The proof is obtained by differentiating the cutoff equations $\overline{k}_G$ and $\underline{k}_G$ defined in the previous proof and verifying the respective sign. Therefore, an increase in the emissions taxation $t$ increases $\overline{k}_G$ and $\underline{k}_G$. The positive sign is guaranteed by the non-negative conditions $4-3c+2t \geq 0$ and $4+3c-10t \geq 0$ of the "partial green" model. These conditions are necessary to guarantee that in the "partial green" model all equilibrium values are positive. These same conditions also guarantee that an increase in the unit production subsidy, which is a reduction in the value of $c$, increases $\overline{k}_G$ and $\underline{k}_G$. Note that these results can also be directly seen in the expressions of $\overline{k}_G$ and $\underline{k}_G$, without the need to compute the derivative and verify the respective sign.

**Proof of Proposition 6:** *Just compare the prices under the three different scenarios.* In other words, $p_{vL}^* \geq p_{hG}^*$ for any $c \geq 0$, while $p_{hD}^* \geq p_{vF}^*$ if $c \leq 4$. Both conditions are guaranteed because $c \in [0,1]$. Finally, $p_{hG}^* \geq p_{hD}^*$ always.

**Proof of Proposition 7:** *Just compare the environmental damages found in Proposition 1, 2 and 3 under* the Pigouvian tax scheme (i.e., under $t = c$).

**Proof of Proposition 8:** Just compare the utilities under the three different scenarios under $t = c$. In other words, $u_{hG}^* \geq u_v^*$ if $c \leq 4(-17+2\sqrt{151})/21$, while $u_v^* \geq u_{hG}^*$ if $c \leq 4(17+6\sqrt{11})/107$. Both conditions are guaranteed for $c \leq 1$.

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