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THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

# Three Essays on Anti-consumerism, Anti-hedonism and Environmentalism, and Economic Growth.

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# Introduction

The dissertation includes three chapters that belong to two fields of study: environmental industrial organization and economic growth. While distinct in its domain, each field interweaves to understand the complex picture of the modern economic landscape, characterized by rapid environmental shifts and technological advancements. Taken together, they allow the thesis to offer a substantial contribution to the study of sustainable economic growth, one of the central objectives of the current political agenda.

The first field focuses on the strategic interaction between consumers and firms, offering a detailed view of the market and environmental consequences of the increasing influence of environmental doctrines. The literature has given this topic growing attention, especially given the salience of environmental discourse on the political agenda and the requests environmental movements have promoted. The first two chapters of the dissertation analyze the validity of the theses supporting the need to shift consumption choices towards environmentally friendly products or the appeal for reducing consumption to improve the environment. The most significant contribution to the literature is identifying and explaining unexpected effects, even harmful under certain conditions, both on the market and the environment. The second field compares the impact of different models, time windows, and forecasting strategies on the accuracy of a set of empirical models for economic growth forecasting. Within the reference literature, this topic is the subject of considerable extension, where more consolidated theories and models are evaluated and extended with methodologies belonging to machine learning. The third chapter compares machine learning, linear, and autoregressive models to establish which is the most accurate in economic growth forecasting. The chapter contributes to the literature by showing that a model based on machine learning can outperform more traditional and autoregressive ones, especially in the absence of auxiliary explanatory variables.

The first chapter studies the effects that *environmentalism* and *anti-hedonism*, intended as environmental doctrines, have on the market and the environmental consequences. The analysis uses a vertical differentiation model where two firms produce goods differentiated over the hedonic and environmental attributes. Consumers are heterogeneous in their willingness to pay for these attributes. Firms' strategic decisions and environmental doctrines affect consumers' choices, which, in turn, determine equilibrium prices, qualities, market shares, profits, consumer surplus, and social welfare. Considering the ecological footprint of each product and the quantity sold, we derive the equilibrium environmental outcome. We show that when the consumers are prominently environmentalist, the market's environmental footprint is relatively low.

In the second chapter, the dissertation shifts focus to *anti-consumerism*, exploring its potential as a lever in policy formulation. The study develops within a model of horizontal differentiation, in which two companies produce goods that consumers value differently depending on their heterogeneous tastes. For goods production, firms face costs. At the same time, consumers evaluate purchasing the goods depending on the gross surplus they would obtain, the prices, the transportation cost, and the distance between the variety of the goods produced from their ideal variety. We compare the benchmark model with two possible scenarios obtained by introducing a demand-side environmental policy based on the environmental doctrine of anti-consumerism. In the first case, this policy reduces the utility that consumers receive by purchasing a good, figuratively behaving like a punitive instrument - a *stick*. In contrast, the second case features an increase in the satisfaction of individuals who choose not to purchase any good acting like a rewarding instrument - a *carrot*. The market equilibrium obtained from the choices of firms and consumers consists of determining prices, market shares, profits, consumer surplus, and social welfare. We show that introducing relatively low levels of anti-consumerism policies does not affect aggregate production when the benchmark market features a high gross product surplus. However, if the levels are sufficiently high, reducing consumption and production levels is possible. In the case of the stick, this is generally detrimental to firms and consumers. Then, this policy could only be desirable with a sufficient decrease in environmental damage. In the case of the carrot, in addition to reducing consumption levels, it is possible to compensate for the losses on the consumer and firm side with the satisfaction of individuals who choose not to buy. The policy mix of stick and carrot is similar to that of the carrot, with the only difference being that the market is more sensitive to anti-consumerism.

The third chapter compares the accuracy of machine learning, linear, and autoregressive models in forecasting the United States' real GDP. The information set for the reference country includes the yield curve, which is composed of treasury bills and government bonds, from which we compute the curve level, slope, and curvature. In addition to real GDP, we include the consumer price index, manufacturing capacity utilization, unemployment rate, and federal funds rate. We aggregate the time series quarterly to match the real GDP frequency. Moreover, the data spans from 1976 to 2020. We compute the predictions for the last quarters by training models only on a subset of data that does not include such quarters. Then, we compare the predictions with the actual data not included in the models to obtain comparable error metrics. The size and temporal location of the data subsets vary, generating different forecast time windows. In the comparison, we evaluate different combinations of the information set and forecasting strategies to predict single and multiple periods. We find that the K-Nearest Neighbor (KNN) machine learning model performs better than traditional time series models when forecasting single periods, while the latter is more accurate for multiple periods, especially with the inclusion of the yield curve proxies paired with macroeconomic indicators. Furthermore, the chapter justifies the choice of regression methodology over classification, as the latter can generate unexpected problems when combined with filters to determine the business cycle.

# Chapter 1

# The Unexpected Effects of Anti-hedonism and Environmentalism

## 1.1 Introduction

Market products exhibit differentiation.[1] Luxury sports cars are faster and provide consumers with a much wider range of accessories and kits that are exclusively designed, with better tech features and more sophisticated sound systems than economic ones. Similarly, premium smartphones boast enhanced core communication features, a wider range of apps and gadgets with superior functionality, distinguishing them from older or less advanced variants. In essence, certain products exhibit higher hedonic qualities than their standard counterparts.

For a long time, the cultural paradigm of *hedonism* has pushed forward the idea that possessing goods of high hedonic quality is a direct gateway for individuals to obtain admiration and respect in society (e.g., Frank [1985], Bagwell and Bernheim [1996]). The decision to purchase certain goods to signal personal wealth and attain elevated social status is a topic of widespread debate, with roots tracing back to Rae [1834]'s seminal contribution and, nearly a century later, to Veblen [1899]'s renowned treatise on conspicuous consumption.[2] However, a growing body of research has begun to challenge the unidimensional view, according to which accumulating highly performing goods in terms of quality warrants individuals' happiness or higher social status. There are several reasons which can explain such a change of paradigm.

On one hand, *environmentalism has become widely pervasive,* emphasizing socially commendable behavior towards the environment.[3] Therefore, when consumers choose environmentally friendly goods, they may experience psychological benefits beyond the mere satisfaction of material needs offered by the products, leading to an increase in their willingness to pay for the environmental quality of goods.[4] As an example, in 2007, the *New York Times* reported the top five reasons why Toyota Prius owners bought their hybrid cars. The main reason was that "it shows the world that its owner cares".[5]

[1]This chapter extends Maccarrone et al. [2023]. I acknowledge Marco Marini and Ornella Tarola's contributions.

[2]This issue has been discussed by, among others, Leibenstein [1950], Corneo and Jeanne [1997], Grilo et al. [2001].

[3]For an extended survey on the evolution of environmental values see, for instance, Dietz et al. [2005]. For a recent analysis of environmentalism and pollution damage, see Chander and Muthukrishnan [2015].

[4]For further insights on this topic, see, for example, Lombardini-Riipinen [2005], Bénabou and Tirole [2006], Mantovani et al. [2016], Marini et al. [2022], Ambec and De Donder [2022].

[5]The literature has identified several mechanisms that generate psychological benefits from the consumption

On the other hand, and in parallel with the activism for reducing consumers' carbon footprint, movements supporting a new "frugal living" have emerged (e.g., Miles [1998], Stearns [2006]). Although these movements can manifest in various forms, the most palpable protest is directed against the consumption of goods with high *hedonic* quality, in favor of less resource-wasting variants (*anti-hedonism*).

By exploring consumer behavior in presence of *social drivers* such as *environmentalism* and *anti-hedonism*, our aim is to uncover how they affect the environmental surplus of the market as well as welfare through the decisions made by firms regarding product qualities and pricing strategies. To this aim, we introduce a model of vertical product differentiation in which two firms produce two goods (one each), differentiated along an *intrinsic* or *hedonic* and an *environmental* dimension.[6] We consider a two-stage game where firms first define their qualities and then compete in prices. We observe that at the equilibrium, goods are differentiated along a unique dimension, either the environmental or the hedonic quality. This finding is in line with the literature on product differentiation with two dimensions of quality (e.g., Vandenbosch and Weinberg [1995]). Our analysis, however, introduces a novel perspective by demonstrating that the environmental surplus is dramatically affected by these social drivers (environmentalism and anti-hedonism) and reaches its peak when environmentalism is not excessively strong.

In a nutshell, we find that *in a market where consumers prioritize hedonic concerns,* if the gap *between the highest hedonic quality and the minimal acceptable quality* is sufficiently low, anti-hedonism reduces consumer surplus. This reduction occurs despite lower prices and is due to lower consumption satisfaction. In this scenario, environmentalism positively affects consumer surplus. However, when it turns out to be so high that *consumers prioritize environmental concerns, then environmentalism can negatively affect consumers surplus.* The economic reason is that *environmentalism magnifies firms' market power and it can result in an increase in equilibrium prices.* Moreover, *advocating for environmentalism over hedonism can result in a significantly lower environmental surplus.*

These findings open the door to some policy considerations. Contrary to a common wisdom, the ecological surplus of the market does not always benefit from environmental campaigns. Even more paradoxically, anti-hedonism campaigns may penalize consumers since their depressive effect on prices does not compensate for the loss in consumers' gross utility. Thus, when implementing policy tools, the policymakers must clearly define their primary objective, since it may happen that enhancing the traditional components of a social welfare function, i.e., consumer surplus and environmental surplus may not always align perfectly.

### 1.1.1 Related Literature

From a modelling viewpoint, our setting is close to Vandenbosch and Weinberg [1995]. They develop a detailed analysis of a market where goods are differentiated along two dimensions and consider, in a two-stage game analysis, that two firms compete first on product positions and then on price,

of environmentally friendly goods. Environmentally conscious consumers may face social stigma when purchasing polluting goods [Kotchen and Moore, 2007], while simultaneously receiving social esteem among peers through pro-environmental consumption [Sexton and Sexton, 2014]. Additionally, a substantial body of economic literature has demonstrated that individuals tend to adhere to group norms (e.g., Akerlof and Kranton [2000], Sobel [2005]). In many communities, these group norms revolve around environmentalism [Dietz et al., 2005, Peattie, 2010].

[6]As in Burani and Mantovani [2024], we use intrinsic or hedonic as synonimous.

absent costs.[7] We borrow from them the strategic selection of product positions and prices by firms in the absence of costs along two dimensions. However, we introduce two additional parameters which represent the strength of (anti-)hedonism and environmentalism freely circulating in market. To the best of our knowledge, our paper is the first to jointly tackle the role of *environmentalism* and *hedonism* in a *vertically differentiated* setting with *two dimensions* of qualities. In our model, the levels of these forces shape consumers' preferences in proportion to their initial willingness to pay for the environmental and hedonic quality of the goods, respectively.

This ingredient opens the door to some policy implications that go beyond the scope of the above-evoked papers aligning our analysis with another body of literature that examines the ecological footprint of markets where products are vertically differentiated based on their environmental quality. However, in this literature, unlike our setting, the market is viewed as a segment, as the quality ladder along which products are ranked is characterized by a single dimension (see, on this line, Moraga-Gonzalez and Padron-Fumero [2002], Bansal and Gangopadhyay [2003], Rodríguez-Ibeas [2003], Amacher et al. [2004], Conrad [2005], Lombardini-Riipinen [2005], Bansal [2008]). There exist some contributions dealing with two dimensions of quality. For example, Mantovani et al. [2016], similarly to Garella and Lambertini [2014] assume that the quality of products develops along two dimensions, a hedonic and an environmental dimension. Nonetheless, the willingness to pay for the environmental attribute is not consumer-specific but related to market as a whole.

The paper is organized as follows. The model is illustrated in Section 2, whereas Section 3 describes the game and the equilibrium market configuration. In Section 4, we illustrate the role of environmentalism and anti-hedonism in the market and examine some of the welfare properties of the model. Finally, we briefly conclude our analysis in Section 5. All major proofs are relegated in the Appendices.

## 1.2 Two-Characteristic Model

We consider a market with a unit mass of consumers. In line with the existing literature [Mussa and Rosen, 1978, Gabszewicz and Thisse, 1979, Shaked and Sutton, 1983, Tirole, 1988], we assume that the product is indivisible and that each consumer always buys one unit of this product (for instance because it is an indispensable good), so that the market is covered. Full market coverage eliminates any aggregate demand effects from changes in environmentalism and anti-hedonism, thus allowing to focus on the purely strategic effects of competition. As in Neven and Thisse [1989], Vandenbosch and Weinberg [1995], Lauga and Ofek [2011], Novo-Peteiro [2020], we consider a two-dimensional setting where, for our purpose, consumers are heterogeneous in their attitudes toward the *hedonic* and the *environmental* quality of products. Formally, every consumer decides whether to buy one unit of a good from one of two firms $i = 1, 2$, thus gaining an indirect utility function equal to

$$U_i(\theta_\gamma, \theta_\varepsilon) = \quad R + \gamma \cdot \theta_\gamma q_i + \varepsilon \cdot \theta_\varepsilon e_i - p_i \quad \text{when consuming good } i = 1, 2. \tag{1.1}$$

Every consumer is heterogeneous in $\theta_\gamma$ which is uniformly distributed in $[0, 1]$ and that denotes her willingness to pay (henceforth WTP) for the *hedonic quality* $q_i$ of good $i$, with $q_i \in [q_{\min}, q_{\max}]$ and

[7] Following a similar formal approach, Lauga and Ofek [2011] delve into how costs impact firms' decision-making at equilibrium. In a similar vein, Barigozzi and Ma [2018], departing from Vandenboschand and Weinber (1995)'s assumption of zero production cost, introduce a strictly convex quality costs.

$q_{\min} > 0$. Similarly, $\theta_\varepsilon$ is uniformly (and independently of $\theta_\gamma$) distributed in $[0, 1]$ and measures every consumer's willingness to pay for the *environmental quality* $e_i$ of good $i$, with $e_i \in [e_{\min}, e_{\max}]$ and $e_{\min} > 0$. In addition, let $\gamma \in (0, \infty)$ express the level of *hedonism* existing in society and $\varepsilon \in (0, \infty)$, the existing level of *environmentalism.* Hedonism and environmentalism can be intended as doctrines pushing the preferences for goods with high hedonic or environmental quality, respectively. *Ceteris paribus*, a reduction in either $\gamma$ or $\varepsilon$ from their initial values corresponds to a drop of consumers' willingness to pay for the hedonic or environmental quality of goods, respectively. For any given $\gamma$ and $\varepsilon$, this decline is more pronounced when consumers' willingness to pay (WTP) is higher. Put differently, given the functional form of the utility function, whenever hedonism becomes weaker, the variant with higher hedonic quality is relatively more adversely affected. Finally, $R$ represents each consumer's reservation utility, which is exogenously given and positive. As a result, each consumer is represented geometrically by a single point of a unit square of coordinates $(\theta_\gamma, \theta_\varepsilon)$. The next definition characterizes the different situations that can occur for given consumers' preferences.

**Definition 1** *(i) The two goods of firms $i = 1, 2$ with $j \neq i$ are aligned if $q_i > q_j$ and $e_i > e_j$. (ii) The two goods are misaligned if $q_i > q_j$ and $e_i < e_j$ . (iii) The two goods are weakly (mis-)aligned if either $q_i > q_j$ and $e_i \geq e_j$ or $q_i \geq q_j$ and $e_i > e_j$.*

The aligned case may be observed, e.g., when a hybrid or electric car is also endowed with a powerful engine as well as, say, a comfortable interior design. In contrast, the case of misalignment typically occurs in the case of a beautiful and highly performing car having a bad environmental impact.

Consider a firm $i = 1, 2$ for which $e_i > e_j$, with $j \neq i$. It can be defined as *green* (with its rival as *brown*). Similarly, if $q_i > q_j$, it can be designated as the *high-quality* firm (with the rival being the *low-quality* firm).[8]

Given that consumers are displaced in a unit square, those among them with a high WTP for the hedonic (environmental) quality and lower for the environmental (hedonic) quality of the goods are located at the south-east (resp. north-west) of the square and are individuals who are *prominently* interested in the hedonic (resp. environmental) quality of goods: in brief, they are highly sensitive to the sirens of hedonism (resp. environmentalism). Obviously, there also exist people who are highly or lowly reactive to *both* attributes. Finally, people located at the center of the square are people who have an *average* interest for both attributes of the goods.

For our purposes, what is relevant in the taxonomy is the resulting indifference line, specifically delineating the boundary encompassing all consumers who are indifferent between the two products. This line partitions the unit square into two, classifying consumers into two groups: those preferring to buy good $i = 1, 2$ and those preferring to buy good $j \neq i$. Solving the simple indifference condition:

$$R + \gamma\theta_\gamma q_i + \varepsilon\theta_\varepsilon e_i - p_i = R + \gamma\theta_\gamma q_j + \varepsilon\theta_\varepsilon e_j - p_j \tag{1.2}$$

yields the following *indifference line*:

$$\theta_\varepsilon(\theta_\gamma) = \frac{p_i - p_j}{\varepsilon e} - \frac{\gamma q}{\varepsilon e}\theta_\gamma, \tag{1.3}$$

[8]This second attribute $q_i$ is the usual attribute of vertical differentiation, intended as *intrinsic* or *hedonic* quality.

where, henceforth, $e \equiv (e_i - e_j)$ denotes the existing the environmental gap between the products sold by the two firms, whereas $q \equiv (q_i - q_j)$ indicates their hedonic gap. For any $(e_i - e_j) \gtreqless 0$ and $(q_i - q_j) \gtreqless 0$, the slope of the indifference line can easily be obtained as

$$\frac{d\theta_\varepsilon(\theta_\gamma)}{d\theta_\gamma} = -\frac{\gamma q}{\varepsilon e}.$$

For example, for $e > 0$, the slope of the indifference line depends on the sign of $q \gtreqless 0$: It follows that the indifference line is, in turn, positively sloped when goods are *misaligned* and negatively sloped when they are *aligned*.[9]

When, instead, either $q = 0$ or $e = 0$, the indifference line simplifies into a line that runs parallel to either the $\theta_\gamma$- or the $\theta_\varepsilon$-axis, respectively. With this in mind, let us introduce the following definition:[10]

**Definition 2** *The market is characterized by (i)* environmental dominance *if* $\varepsilon > \frac{q}{e}\gamma$ *(resp.* $\varepsilon > -\frac{q}{e}\gamma$*) under good* alignement *(resp.* misalignement*); (ii)* hedonic dominance *if* $\gamma > \varepsilon\frac{e}{q}$ *(resp* $\gamma > -\varepsilon\frac{e}{q}$*) under good* alignement *(resp.* misalignement*).*

From the above definition, it is clear that the environmental or hedonic dominance between the two goods depends on two features: the hedonic (and environmental) quality gap between products on the one hand, and the strength of environmentalism and hedonism in the market, on the other.

From (1.3), the vertical intercepts of the indifference line are simply given by

$$\theta_\varepsilon(0) = \frac{p_i - p_j}{\varepsilon e}, \text{ and } \theta_\varepsilon(1) = \frac{p_i - p_j}{\varepsilon e} - \frac{q\gamma}{\varepsilon e}, \tag{1.4}$$

whereas, in turn, the horizontal intercepts are

$$\theta_\gamma(0) = \frac{p_i - p_j}{\gamma q}, \text{ and } \theta_\gamma(1) = \frac{p_i - p_j}{\gamma q} - \frac{\varepsilon e}{\gamma q}. \tag{1.5}$$

Figure 1 below illustrates the indifference line in the two cases of *aligned* (upper panels (a) and (b)) and *misaligned* attributes (lower panels (d) and (e)) under either *environmental* (continuous line) or *hedonic dominance* (dashed line). Furthermore, we depict a third scenario for both *weak alignment* (panel c) and *weak misalignment* (panel f), where the indifference line simplifies into a line parallel to either the $\theta_\gamma$- or the $\theta_\varepsilon$-axis, respectively. In this case, the quality gap is strictly positive in a single dimension, since either $e_i = e_j$ or $q_i = q_j$. Specifically, by way of example, in the weak alignment case, we represent an indifference line capturing $q_i = q_j$ and $e_i > e_j$. In the misalignment case, we represent an indifference line capturing $q_i < q_j$ and $e_i = e_j$.

We can now introduce the following two-stage game. Firstly, firms choose the equilibrium qualities of their variant, given the minimal quality required for a variant to be marketed along the spectrum of the technologically feasible quality, i.e. $q_i \in [q_{\min}, q_{\max}]$ and $e_i \in [e_{\min}, e_{\max}]$. Secondly, they compete in prices.

We are now in the position to derive the demand functions in each case.

[9]This analysis closely resembles that of Vandenbosh and Weiberg (1995). Regarding the indifference line, they introduce the concept of *angle of competition*, which illustrates the firms' relative positioning advantage and is employed to ascertain the demands for each product. Each angle delineates the array of alternative product positionings while maintaining the same relative separation.

[10]This taxonomy will be used for the characterization of Nash equilibria (see, Section 3).

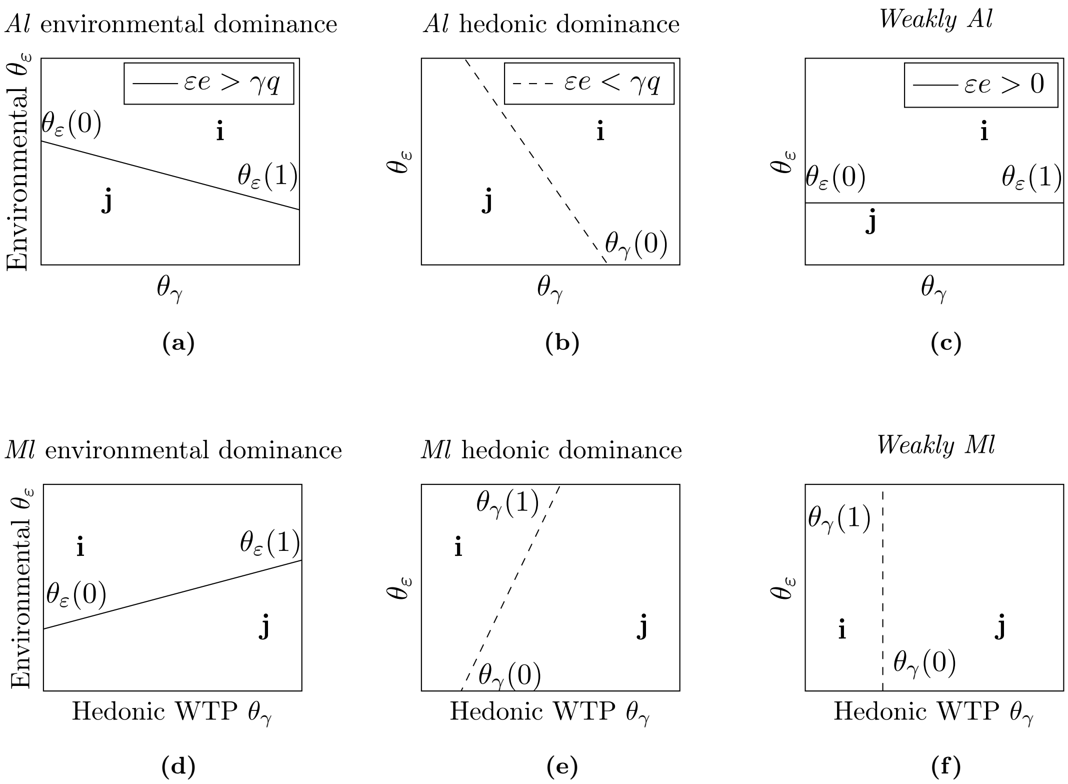


**Figure 1.1:** The indifference line under different types of alignment and dominance.

### 1.2.1 Demand functions

From the analysis of the indifference line, it turns out that there are several situations for which is relevant to derive the demand functions of the two firms: (i) *aligned goods* and *environmental dominance*; (ii) *aligned goods* and *hedonic dominance*; (iii) *misaligned goods* and *hedonic dominance*; (iv) *misaligned goods* and *environmental dominance*; (v) *weakly (mis)aligned* case with *environmental dominance*; (vi) *weakly (mis)aligned* case with *hedonic dominance*.[11]

By means of the indifference line (1.3), we can obtain the demand function of a firm as a function of its own and rival's price. A negatively (or positively) sloped indifference line intersects the square and divides the unit mass of consumers into two distinct regions, thereby delineating the demand functions of the firms in different regions of the square.

As a means of example, we focus hereafter on the case where $e > 0$ and $q > 0$, where, for simplicity, we set $i = 1$ and $j = 2$. Then, looking at Figure 1 panel (a), we observe that the demand for firm 1 in the case of alignment and environmental dominance is given by the region lying above the indifference line. Symmetrically, the demand for firm 2 is given by the region below this line. As the indifference line can shift within the square, the region representing the demand for firms adjusts accordingly. Following Vandenbosch and Weinberg (1995), to describe any possible demand configuration determined by the indifference line, we consider firms' prices at all corners of the square. In the case of alignment, they can be obtained as

$$p_2(0,0) = p_1,\, p_2(1,0) = p_1 - \gamma q$$

[11] In Appendix 1, we detail all different cases.

and

$$p_2(0,1) = p_1 - \varepsilon e,\ p_2(1,1) = p_1 - \varepsilon e - \gamma q,$$

respectively. So, in the region occurring for the price range $p_2 \in [p_1 - q\gamma, p_1]$, denoted as region $I$, the demand for firm 2 obtains as:

$$D_2^I(p_1,p_2) = \frac{\theta_\gamma(0)\cdot\theta_\varepsilon(0)}{2} = \frac{(p_1-p_2)^2}{2\gamma q\varepsilon e}. \tag{1.6}$$

Alternatively, in region $II$, occurring for $p_2 \in [p_1 - \varepsilon e, p_1 - q\gamma]$, the demand function for firm $j$ corresponds to the area of a trapezoid having bases, respectively, of length $\theta_\varepsilon(0)$ and $\theta_\varepsilon(1)$ and height 1. This is,

$$D_2^{II}(p_1,p_2) = \frac{1}{2}\left(\theta_\varepsilon(0) + \theta_\varepsilon(1)\right) = \frac{2\,(p_1-p_2) - q\gamma}{2\varepsilon e}. \tag{1.7}$$

Finally, in region $III$, defined by $p_2 \in [p_1 - q\gamma - \varepsilon e, p_1 - \varepsilon e]$, firm 2's demand writes as

$$D_2^{III}(p_1,p_2) = 1 - \frac{(1-\theta_\gamma(1))(1-\theta_\varepsilon(1))}{2} = \frac{\varepsilon e\,(2(p_1-p_2) - \varepsilon e) - (p_1 - p_2 - q\gamma)^2}{2\gamma q\varepsilon e}. \tag{1.8}$$

The demand of firm 1 for every different region $k = I, II, III$ (i.e., price ranges), can immediately be obtained exploiting the fact that $D_1^k(p_1,p_2) = 1 - D_2^k(p_1,p_2)$ . We relegate in Appendix 1 the derivation of firms' demands in all remaining cases.[12]

## 1.3 The Game

We can now let firms play the two-stage game. At stage 1, firms choose the product quality attributes $e_i$ and $q_i$, for $i = 1,2$. At stage 2, they set prices. Products are assumed to have a constant marginal cost normalized to zero regardless of product position. This assumption does not align with real-world conditions. Still, it simplifies the analysis and enables us to focus on the strategic effects of product positioning.[13] Moreover, it can be generalized to the case where costs are not very high. In particular, even when considering separable linear costs for quality production, i.e., given by the following: $\Pi_i(\mathbf{e},\mathbf{q}) = p_i(\mathbf{e},\mathbf{q})\cdot D_i(\mathbf{e},\mathbf{q}) - c\,(e_i + q_i)$ for $i = 1,2$, where $\mathbf{e} = (e_1, e_2)$ and $\mathbf{q} = (q_1, q_2)$ denote the vectors of hedonic and environmental qualities, the results remain the same as long as these costs are sufficiently low.[14]

Accordingly, firms payoffs are, for $i = 1,2$ and $j \neq i$, simply given by:

$$\Pi_i(\mathbf{e},\mathbf{q}) = p_i(\mathbf{e},\mathbf{q})\cdot D_i(p_i(\mathbf{e},\mathbf{q}), p_j(\mathbf{e},\mathbf{q})). \tag{1.9}$$

[12] Since in what follows we draw from Vandenbosch and Weinberg [1995], we direct the interested readers to their work for a more detailed derivation of demand functions in this bi-dimensional vertical product differentiation model (VPD).

[13] In the literature of VPD with two attributes, we share this assumption with Vandenbosch and Weinberg [1995], Novo-Peteiro [2020].

[14] We will prove in the following sections that at equilibrium, the *max-min* principle holds, with firms opting for maximum differentiation in one quality dimension and minimal differentiation in the other. As costs increase, both firms' strategic choice of qualities shifts to lower qualities, giving rise to different combinations of maximum and minimum differentiation. The proof is available upon request.

### 1.3.1 Price Stage

In order to characterize all market configurations occurring at the subgame perfect Nash equilibrium of the two-stage game, we proceed by backward induction. Firstly, given firms payoffs as in (1.9), we envisage the existing *candidate Nash equilibrium prices* $p_i^*(\mathbf{e},\mathbf{q})$ and $p_j^*(\mathbf{e},\mathbf{q})$*,* for any possible demand configuration. Secondly, we check whether the obtained candidate equilibrium prices are consistent with the demand configuration. In particular, we verify whether these prices belong to the price range that characterizes the specific demand configurations used to derive the candidate equilibrium price in profit maximization. If these prices do not fall within these ranges, we conclude that at least one firm is incentivized to deviate profitably from the candidate equilibrium price. This invalidates the possibility for the price profile to be part of the Nash equilibrium. Then, we move to the quality stage.

In the following Lemmata, we show that, for each specific situation descending from Definition 1 and 2, there exists a unique Nash equilibrium *profile* $(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q}))$ characterized as follows.[15]

**Lemma 1**. *Assume that goods are aligned. There exists a unique interior price equilibrium profile* $(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q}))$ *such that:*

*(i) if* $\varepsilon > q\gamma/e$ then $p_i^*(\mathbf{e},\mathbf{q}) \in [p_j, p_j + q\gamma]$ and $p_j^*(\mathbf{e},\mathbf{q}) \in [p_i - q\gamma, p_i]$*;*

*(ii)* if $\gamma > e\varepsilon/q$ then $p_i^*(\mathbf{e},\mathbf{q}) \in [p_j, p_j + \varepsilon e]$ and $p_j^*(\mathbf{e},\mathbf{q}) \in [p_i - \varepsilon e, p_i]$;

*(iii) if* $\varepsilon > 2q\gamma/e$ then $p_i^*(\mathbf{e},\mathbf{q}) \in [p_j + q\gamma, p_j + \varepsilon e]$ and $p_j^*(\mathbf{e},\mathbf{q}) \in [p_i - \varepsilon e, p_i - q\gamma]$*;*

*(iv) if* $\gamma > 2e\varepsilon/q$ then $p_i^*(\mathbf{e},\mathbf{q}) \in [p_j + \varepsilon e, p_j + q\gamma]$ and $p_j^*(\mathbf{e},\mathbf{q}) \in [p_i - q\gamma, p_i - e\varepsilon]$.

**Lemma 2**. *Let now goods be misaligned. There exists a unique interior price equilibrium profile* $(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q}))$ *such that:*

(i) *if* $\varepsilon > -q\gamma/e$ then $p_i^*(\mathbf{e},\mathbf{q}) \in [p_j, p_j + \varepsilon e - q\gamma]$ and $p_j^*(\mathbf{e},\mathbf{q}) \in [p_i - \varepsilon e + q\gamma, p_i]$*;*

(ii) if $\gamma > -e\varepsilon/q$ then $p_i^*(\mathbf{e},\mathbf{q}) \in [p_j, p_j - e\varepsilon + q\gamma]$ and $p_j^*(\mathbf{e},\mathbf{q}) \in [p_i + e\varepsilon - q\gamma, p_i]$.

**Lemma 3**. Finally, let goods be *weakly mis(aligned).There exists a unique price equilibrium profile* $(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q}))$ *such that:*

(i) *if* $\varepsilon e > 0$ then $p_i^*(\mathbf{e},\mathbf{q}) \in [p_j, p_j + \varepsilon e]$ and $p_j^*(\mathbf{e},\mathbf{q}) \in [p_i, p_i - \varepsilon e]$*;*

(ii) if $q\gamma > 0$ then $p_i^*(\mathbf{e},\mathbf{q}) \in [p_j, p_j + q\gamma]$ and $p_j^*(\mathbf{e},\mathbf{q}) \in [p_i, p_i - q\gamma]$.

The above Lemmata, whose proofs are relegated in Appendix 2, help to characterize all different Nash equilibria arising at the price stage for all different cases of *environmental* and *hedonic dominance* with (weakly) *aligned* or (weakly) *misaligned* attributes.[16]

### 1.3.2 Quality Stage

We can now study the behavior of the two firms at the quality stage.

We prove in Appendix 3 that, under *environmental dominance*, the Nash equilibrium qualities

[15] For simplicity, in all Lemmata and Propositions that follow, we will adopt the convention to denote as $i = 1, 2$ (and $j \neq i$ its rival), the "dominant firm", i.e., the firm with either both higher qualities under aligned attributes ($q_i > q_j$ and $e_i > e_j$) or with the most relevant quality higher under misalignment, namely with $q_i > q_j$ (and $e_i < e_j$) under *hedonic dominance* and $e_i > e_j$ (and $q_i < q_j$) under *environmental dominance*. Thus, in all cases the equilibrium prices will be such that; $p_i^*(\mathbf{e},\mathbf{q}) > p_j^*(\mathbf{e},\mathbf{q})$.

[16] Notice that the Appendix details, for each case, the exact equilibrium prices selected by the firms.

are, for $i = 1, 2$ and $i \neq j$:[17]

$$e_i^* = e_{\max}, \;\; q_i^* = q_{\max} \text{ and } e_j^* = e_{\min}, \; q_j^* = q_{\max}, \tag{1.10}$$

whereas, in the case with *hedonic dominance*:

$$e_i^* = e_{\max}, \; q_i^* = q_{\max} \text{ and } e_j^* = e_{\max}, \; q_j^* = q_{\min}. \tag{1.11}$$

It becomes apparent from the above analysis that although there are two dimensions available, firms opt to differentiate their products along only one dimension.

The rationale behind this phenomenon is twofold, and to elucidate it, one needs only to examine a standard model of VPD. The selection of equilibrium qualities in a standard model of VPD is intricately linked to the decision regarding the quality gap and consumers' willingness to pay for qualities.

Widening the quality gap in a model of VPD with market coverage results from two distinct sets of considerations. *On the one hand*, the quality gap enhances firms' market power by fostering increased product differentiation. This positively impacts the pricing of both high and low-quality goods, driving prices upward (*upward price effect*). *On the other hand*, in the pursuit of product differentiation, the low-quality firm inevitably compromises on the quality of its offering. Consequently, this choice leads to a reduction in the equilibrium price of the low-quality product. Given that prices are strategic complements, a decrease in this price results in a corresponding reduction in the price of the high-quality good as well (*downward price effect*).

As far as the willingness to pay for the products is concerned, the higher the willingness to pay, the greater the resulting equilibrium prices, *ceteris paribus* (*upward price effect*). In a model of VPD with two dimensions, such as ours, the willingness to pay for environmental quality differs from that for hedonic quality. Firms will choose to differentiate their products in the dimension for which the willingness to pay is higher since this will have a positive and stronger impact on prices, i.e. a stronger *upward price effect.*

The relative strength of each effect on prices determines the profitability of positioning the low-quality goods further away from their high-quality counterpart, thereby affecting the equilibrium quality gap.

The choice of differentiating along a single dimension is not new in the literature on product differentiation. In Irmen and Thisse [1998], it is found that in a context of a simple model *à la* Hotelling [1929] with quadratic transportation costs and several dimensions, firms choose to maximize the differentiation along one dimension, while minimizing differentiation along the others. They explain that differentiating along a single dimension is enough to guarantee market power and to enable firms to enjoy the advantages of a central location in all other characteristics. In a setting of vertical product differentiation, a similar result is found. In Vandenbosch and Weinberg [1995], the Max-Min principle, wherein firms select the maximum level of differentiation in one dimension and the minimum level in another, is demonstrated to belong to a set of equilibria. The economic *rationale* behind their equilibrium is akin to that observed in Irmen and Thisse [1998]. While a

[17] Let us remind here, for convenience, that *environmental dominance* corresponds, alternatively, to $\varepsilon > q\gamma/e$ with aligned goods and to $\varepsilon > -q\gamma/e$ with misaligned goods. Once again, notice that we denote with $i = 1, 2$ the firm setting both equilibrium qualities at the maximum level and with $j \neq i$ the firm setting one quality at the maximum and the other at the minimum.

strategic effect motivates firms to differentiate products (as differentiation enhances market power), a demand effect leads to the minimum level of differentiation (as a smaller quality gap results in lower prices and, all else being equal, larger demand for firms).[18]

In our approach, we confirm that firms opt to maintain differentiation along a single dimension, thereby enabling them to preserve market power while mitigating the downward price effect. However, given our emphasis on the influence of social drivers, our results depart from the above cited literature in two main respects. *First*, we prove that firms prioritize differentiation along either the environmental or hedonic quality based on which one commands a higher willingness to pay. This determination is heavily influenced by the dominant social driver. Therefore, it is not solely the quality gap or consumers' willingness to pay that dictates the choice of equilibrium qualities but, rather, the relative strength of environmentalism/hedonism in the market. This, in turn, affects the willingness to pay and, subsequently, firms' profitability in selecting a dimension of differentiation. *Second,* we uncover a paradoxical effect: since the quality choices are driven by the dominant social driver, it is not evident a priori that environmental dominance will lead to a quality choice that is environment enhancing compared to the choice made under hedonic dominance.

To this end, in the following section, we explore the implications of equilibrium quality choices, shedding light on how the presence of social drivers influences the overall market configuration.

### 1.3.3 Market Solution

Now, we are in the position to characterize the market solution arising at the subgame perfect Nash equilibrium of the whole game. In particular, we first consider equilibrium prices and demands, determining the equilibrium profits. Then, we move to the analysis of the environmental surplus of the market, computed as the sum of the market shares of the two product variants, weighted by their environmental qualities. Following Marini et al. [2022], we postulate a linear positive relationship between the amount of the final goods produced and the quantity of emissions in the market. Thus, formally, we define the environmental surplus of the market $E$ as:[19]

$$E = D_i(p_i, p_j) \cdot e_i + D_j(p_i, p_j) \cdot e_j. \tag{1.12}$$

Let, henceforth, for notational convenience, denote by $\hat{e} = (e_{\max} - e_{\min})$ and $\hat{q} = (q_{\max} - q_{\min})$. Plugging the equilibrium qualities (1.10) and (1.11) into price expressions characterized by Lemma 1-3 and detailed in Appendix 2, it is easy to see that, regardless of whether goods are *aligned* or *misaligned*, we obtain the following equilibrium prices

$$p_i^e(\mathbf{e}^*, \mathbf{q}^*) = \frac{2\varepsilon\hat{e}}{3} \text{ and } p_j^e(\mathbf{e}^*, \mathbf{q}^*) = \frac{\varepsilon\hat{e}}{3} \tag{1.13}$$

[18] It is worth noting that the analysis of equilibrium qualities in a multidimensional vertical product differentiation model has been further developed by Barigozzi and Ma [2018]. In their approach, two firms can choose the levels of an arbitrary number of qualities. Equilibrium qualities depend on what they call the *Spence* and *price-reaction effects.* On the one hand, the Spence effect alone is a driver for minimal product differentiation since the lower the gap between qualities, the larger the demand for firms. On the other hand, the price-reaction effect motivates firms to maximal differentiation: in line with Irmen and Thisse [1998], Vandenbosch and Weinberg [1995], a larger quality gap moves, *ceteris paribus*, prices upward.

[19] A similar approach is in Sanin and Zanaj [2011], Ceccantoni et al. [2018]. It is clear that, as long as the market is covered, the demands sum up to one and, therefore, what matters for the level of environmental surplus is the environmental qualities of the goods on the one hand and the size of the *green* firm's market share, and of the *brown* one on the other.

in presence of *environmental* dominance, and

$$p_i^h(\mathbf{e}^*, \mathbf{q}^*) = \frac{2\gamma\hat{q}}{3} \text{ and } p_j^h(\mathbf{e}^*, \mathbf{q}^*) = \frac{\gamma\hat{q}}{3}, \tag{1.14}$$

under *hedonic dominance,* where the superscripts $e$ and $h$ stand for environmental and hedonic dominance, respectively. Whatever the dominance, equilibrium demands are:

$$D_i^*(\mathbf{e}^*, \mathbf{q}^*) = \frac{2}{3} \text{ and } D_j^*(\mathbf{e}^*, \mathbf{q}^*) = \frac{1}{3}. \tag{1.15}$$

Finally, profits can be immediately obtained as:

$$\Pi_i^e(\mathbf{e}^*, \mathbf{q}^*) = \frac{4\varepsilon\hat{e}}{9} \text{ and } \Pi_j^e(\mathbf{e}^*, \mathbf{q}^*) = \frac{\varepsilon\hat{e}}{9} \tag{1.16}$$

under *environmental dominance* and

$$\Pi_i^h(\mathbf{e}^*, \mathbf{q}^*) = \frac{4\gamma\hat{q}}{9} \text{ and } \Pi_i^h(\mathbf{e}^*, \mathbf{q}^*) = \frac{\gamma\hat{q}}{9} \tag{1.17}$$

under *hedonic dominance.*

Two remarks are in order. Firstly, it is worth noting that both equilibrium prices and profits only depend on the “dominant" social driver in the market. Secondly, in contrast with prices, the equilibrium demands are not affected by $\gamma$ and $\varepsilon$.

The reason behind the equilibrium profits being as in (1.16)-(1.17) can be briefly explained as follows. At equilibrium, firms find it optimal to differentiate along a single dimension, either the environmental or the hedonic quality, depending on the dominant social driver. Consequently, the mechanisms operating in the model mimic those observed in a standard vertical product differentiation (VPD) model with a single attribute.

It is worth noting that, in spite of the above mechanism, the magnitude of both social drivers is relevant in that they alter the type of dominance, potentially shifting the market from an equilibrium characterized by one type of dominance to another.

Finally, using (1.13)-(1.15), the equilibrium environmental surplus writes as:

$$E^e(\mathbf{e}^*, \mathbf{q}^*) = \frac{2e_{\max} + e_{\min}}{3} \text{ and } E^h(\mathbf{e}^*, \mathbf{q}^*) = e_{\max} \tag{1.18}$$

at the *environmental* and *hedonic dominance* equilibrium, respectively.

## 1.4 The Influence of Social Drivers

Now, we can describe the effects of social drivers in the market. These effects are analyzed first under the assumption that the market is characterized by a specific dominance, either environmental or hedonic, i.e. the *within equilibrium effects.* Next, we explore how these effects change when the market shifts from one type of dominance to another, moving our analysis to *across equilibria effects.*

### 1.4.1 Within Equilibrium Effects

We begin by examining how environmentalism and hedonism impact firms' profits at equilibrium, and then consider the effects on consumer surplus.

### Firms

By partially differentiating (1.16) and (1.17) with respect to social drivers, we obtain:

**Proposition 3** *(i) Under environmental dominance, an increase in environmentalism unequivocally raises both firms' equilibrium profits, while anti-hedonism has no impact on profits. Conversely, (ii) under hedonic dominance, anti-hedonism unequivocally decreases both firms' equilibrium profits, whereas environmentalism does not affect them.*

These results are rather intuitive. Both environmentalism and (anti-)hedonism have a clear impact on prices, whereas they leave unaffected equilibrium demands. This immediately explains their effects on profits. The economic *rationale* behind this observation can be explained as follows: consider, for example, the scenario where goods are aligned and *environmental dominance* prevails in the market. In this case, it is profitable for firms to pursue maximum differentiation in terms of environmental quality while maintaining uniformity in the hedonic dimension. By maximizing the environmental quality gap, firms can enhance their market power, which is then reflected in the equilibrium prices. Maximizing the hedonic quality gap does not yield the same effect because consumers are less sensitive to this dimension. Consequently, their willingness to pay for the hedonic quality is less motivating for firms compared to the environmental dimension. The role of anti-hedonism can be immediately explained by symmetry in the case of *hedonic dominance*.

### Consumers

We can now analyze the effect of both social drivers on consumers' utilities. For this purpose, we use the standard concept of consumer surplus (CS) which is detailed in Appendix 4.

Using equilibrium prices (1.13) and demands (1.15), we obtain the equilibrium consumer surplus under *environmental dominance*:

$$CS^e(\mathbf{e}^*, \mathbf{q}^*) = R + \frac{9\gamma q_{\max} - \varepsilon\,(2e_{\max} - 11e_{\min})}{18}. \tag{1.19}$$

Thus, the main effects of social drivers on consumer surplus, in this case are the following:

**Proposition 4** *Under* environmental dominance *(i) the environmentalism negatively (positively) affects consumers surplus if the environmental quality gap $\hat{e}$ is sufficiently high (low). Conversely, (ii) the anti-hedonism exerts a negative impact on consumer surplus.*

Notice that under *environmental dominance* both firms' equilibrium prices are positively affected by environmentalism, while they are not affected by the anti-hedonism. As a result, *on the one hand,* a rise in environmentalism hurts consumers due to higher prices and, when the environmental quality gap $\hat{e}$ is high, this negative *price effect* more than offsets the positive impact that environmentalism has on consumers' utility. Therefore, consumers are worse off. The opposite occurs for a low quality gap $\hat{e}$ as, in this case, the price effect is mild and the positive effect of environmentalism on consumers' utility dominates.

*On the other hand,* an increase in anti-hedonism does not yield any effect on prices, so its impact reduces consumer surplus.

The case of *hedonic dominance* works analogously. Plugging equilibrium prices (1.14) and demands (1.15) into consumer surplus (see Appendix 4) yields:

$$CS^h(\mathbf{e}^*, \mathbf{q}^*) = R + \frac{9\varepsilon e_{\max} - \gamma\left(2q_{\max} - 11q_{\min}\right)}{18}. \tag{1.20}$$

**Proposition 5** *Under hedonic dominance, (i) anti-hedonism negatively (positively) affects the consumer surplus if the hedonic quality gap $\hat{q}$ is sufficiently low (high). Conversely, (ii) environmentalism exerts a positive impact on consumer surplus.*

The intuition for these results is analogous to the one highlighted in the case of environmental dominance. Under *hedonic dominance*, Nash equilibrium prices (1.14) depend negatively on anti-hedonism and are not affected by environmentalism. Thus, an increase in anti-hedonism lowers prices, although it also reduces consumers' gross utility. When the hedonic quality gap $\hat{q}$ is sufficiently small, the latter effect of anti-hedonism is not compensated by the former price effect, and consumers are damaged as a result. The opposite occurs under a high hedonic quality gap $\hat{q}$ between goods. In contrast, since environmentalism does not affect the equilibrium prices, its impact is positive on consumer surplus.

Accordingly, it emerges from the above that while environmentalism is mainly consumers enhancing while being consumers detrimental only when $\hat{e}$ is high, anti-hedonism is largely consumers detrimental, while being consumers enhancing only when $\hat{q}$ is high.

We are now in the position to evaluate the effects of social drivers on social welfare. This can be measured as:

$$SW^* = CS^* + \Pi_1^* + \Pi_2^* + E^*. \tag{1.21}$$

As detailed in Appendix 4, since firm profits and consumer expenditures are a transfer from consumers to firms, they do not matter for social welfare. Thus, under *environmental dominance*, social welfare is

$$SW^e(\mathbf{e}^*, \mathbf{q}^*) = R + \frac{9\gamma q_{\max} + \varepsilon(8e_{\max} + e_{\min})}{18} + \frac{2e_{\max} + e_{\min}}{3}, \tag{1.22}$$

whereas, under *hedonic dominance*,

$$SW^h(\mathbf{e}^*, \mathbf{q}^*) = R + \frac{9\varepsilon e_{\max} + \gamma\left(8q_{\max} + q_{\min}\right)}{18} + e_{\max}. \tag{1.23}$$

It immediately follows that:

**Proposition 6** *(i) anti-hedonism always lowers social welfare, whereas (ii) environmentalism always increases it.*

### 1.4.2 Accross Equilibria Effects

However, the above considerations do not account for the possibility of the market switching from one type of dominance to another. In such circumstances, additional considerations are required.

For example, let us consider the market under *hedonic dominance*. In this scenario, we assume that a raise in environmentalism is so strong to move the market to *environmental dominance*.[20] Then, three different effects take place.

*Firms* unambiguously benefit from a change in the dominance, i.e., when the market switches from hedonic to environmental dominance. In Figure 2, (a) and (b), we plot the equilibrium profit as a function of $\varepsilon$: in Figure 2 (a), the environmental quality gap $\hat{e}$ is *"small"*, whereas it is *"large"* in Figure 1 (b).[21] Regardless of the gap, we observe that profits are higher under environmental dominance than hedonic dominance, which is unsurprising. Environmentalism does not affect equilibrium profits under hedonic dominance but increases them both under environmental dominance.

When examining *consumers* (Figure 2 (c) and 2(d)), we observe that consumers are better under environmental dominance when the environmental quality gap is small.

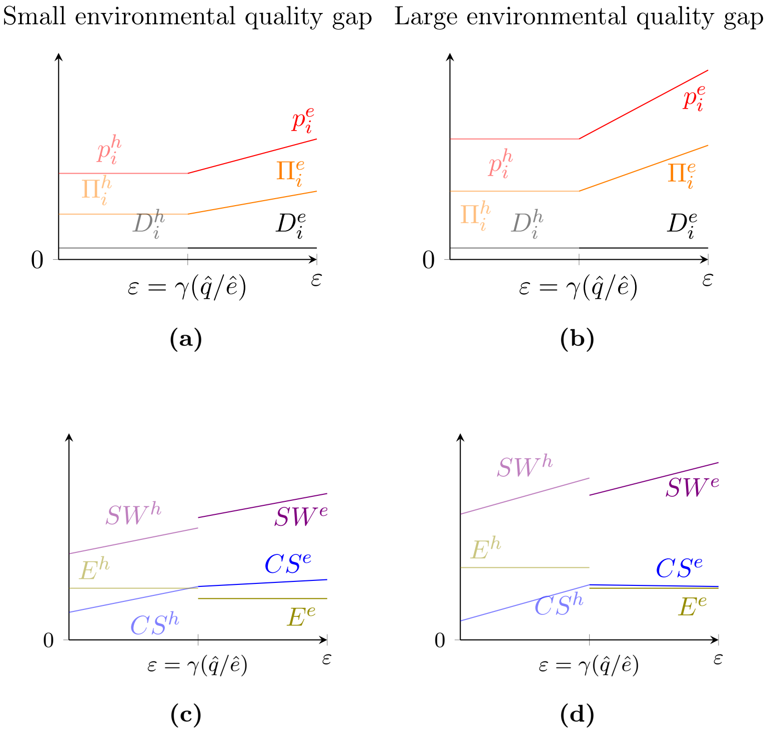


**Figure 1.2:** Social drivers effects on the market.

Let us now focus on how the environmental surplus changes when moving from hedonic to environmental dominance. From standard algebra, by looking at the two expressions in (1.18), we immediately obtain:

$$E^h(\mathbf{e}^*, \mathbf{q}^*) > E^e(\mathbf{e}^*, \mathbf{q}^*)$$

**Proposition 7** *At the equilibrium, the environmental surplus of the market is higher when hedonic dominance prevails compared to the scenario characterized by environmental dominance, regardless of whether goods are aligned or misaligned.*

[20] By symmetry, one can immediately guess the effects when moving from environmental to hedonic dominance. We prefer to focus on the other switch as it captures the recent worldwide trend of consumers willing to purchase cleaner and cleaner variants to save the planet, even sacrificing luxury and better-performing goods.

[21] The gap is small whenever environmentalism positively affects consumers, and it is large otherwise, i.e., when environmentalism negatively affects consumers.

In the case of environmental surplus, we observe a jump (Figure 2 (c) and 2 (d)), so from an environmental view point, hedonic dominance is by far better than environmental dominance. This conclusion may, at first glance, seems counterintuitive.

To capture the economic *rationale* behind the above result, we need to see how the choice of equilibrium qualities is affected by the social drivers $\varepsilon$ and $\gamma$. Since qualities play a pivotal role in determining the ecological footprint of the market, examining the influence of $\varepsilon$ and $\gamma$ on qualities serves as a method to discern the indirect impact that these social drivers have on the ecological footprint. We know from the previous section that firms choose maximal differentiation in environmental (resp. hedonic) quality in the presence of environmental (resp. hedonic) dominance. This is due to the relatively stronger role of environmentalism (hedonism), which magnifies the willingness to pay for environmental (hedonic) quality.[22] This quality choice results in both a clean and a dirty variant being available for sale, whereas in the case of hedonic dominance, both environmental qualities are set at their maximum level. In other words, environmental dominance leads firms to make a profit-maximizing decision that is more detrimental to the environment compared to the decision made under hedonic dominance.

## 1.5 Concluding Remarks

In the paper, we have considered the role of environmentalism and anti-hedonism in the market. We found that in equilibrium, goods are differentiated along a unique dimension in terms of environmental or hedonic quality. Moreover, we obtained that both firms offer the cleanest available variant in less environmentally conscious markets. This result may initially appear paradoxical. However, the unexpected nature of firms' choices regarding environmental qualities becomes clearer upon considering the mechanisms operating within a model of vertical product differentiation. The decision to emphasize the quality gap in the hedonic dimension rather than the environmental dimension is somewhat reasonable when we consider that, in circumstances where environmentalism is not particularly strong, differentiating products along the environmental dimension may not lead to a significant increase in profits. Instead, a substantial differentiation in the hedonic component is likely to generate higher profits when consumers place a higher value on hedonic than environmental issues.

We can draw some policy considerations from the above.

First of all, enhancing environmental awareness does not always translate into a cleaner environment. Our result is new in the literature on vertical product differentiation with two quality dimensions. However, it is reminiscent of the Jevons's paradox, a concept extensively discussed in environmental economics [Allcott, 2011, Murray, 2013, Vivanco et al., 2016] stating that energy-saving policies may increase rather than decrease energy consumption. Moreover, it is confirmed by some theoretical analysis in the field of VPD with a single attribute [Moraga-Gonzalez and Padron-Fumero, 2002, Mantovani et al., 2016, Marini et al., 2022].[23]

[22] Both social forces, environmentalism and anti-hedonism, in this respect, work in the same direction, namely toward a possible environmental dominance, which ultimately deteriorates the equilibrium ecological footprint of the market.

[23] In particular, in Marini et al. [2022] environmentalism allows firms with higher market power that they exert with higher prices. Such an increase lowers the demand for the cleaner firm, resulting in a worse environmental surplus. This effect resembles the one found in this chapter, as environmentalism *indirectly* affects firms' market shares. When environmentalism increases to the extent that it becomes dominant, the environmental surplus worsens.

More explicitly, a public policy increasing consumers' willingness to pay for the cleaner variant always benefits firms. Paradoxically, the positive impact of environmentalism on profits is not confined to the cleaner producer: even the dirtier firm gets a benefit. Environmentalism benefits consumers only if the more polluting producer can market a sufficiently clean good. Otherwise, strongly influencing consumers to raise their willingness to pay for environmental quality does not improve their well-being. Finally, even in the more optimistic scenario where consumers benefit from environmentalism, the environment does not gain.

## 1.6 Appendix

### 1.6.1 Demand Functions

We detail here the construction of firms' demands in all remaining cases not considered above in the main text, where we only considered the case of *aligned attributes* with *environmental dominance*, denoted *case* (i). We deal here with the two firms' demands for the (ii) *aligned* case with *hedonic dominance*, (iii) *misaligned* case with *hedonic dominance*, (iv) *misaligned* case with *environmental dominance*, (v) *weakly (mis)aligned* case with *environmental dominance*, (vi) *weakly (mis)aligned* case with *hedonic dominance.*

**Case (ii)**. For the *aligned* case with *hedonic dominance* (i.e., for $\gamma > e\varepsilon/q$ with $q \equiv (q_i - q_j) > 0$ and $e \equiv (e_i - e_j) > 0$),[24] since in region $I$ and $III$ firms' demands are invariant to the type of (hedonic vs. environmental) *dominance*, they are exactly as in (1.6)-(1.8), although with modified price ranges: $p_i \in [p_j, p_j + \varepsilon e]$ and $p_j \in [p_i - \varepsilon e, p_i]$ for region $I$ and $p_i \in [p_j - q\gamma, p_j - q\gamma + \varepsilon e]$ and $p_j \in [p_i + q\gamma - e\varepsilon, p_i + q\gamma]$ for region $III$. In contrast, in region $II$, the *hedonic dominance* matters and the demands can be computed, specifically as:

$$D_j^{II}(p_i, p_j) = \frac{1}{2}\left(\theta_\gamma(1) + \theta_\gamma(0)\right) = -\frac{2\left(p_i - p_j\right) - e\varepsilon}{2q\gamma} \text{ and } D_i^{II}(p_i, p_j) = 1 - D_j^{II}(p_i, p_j),$$

for $i = 1, 2$ and $j \neq i$. Henceforth, to economize on space, we illustrate only firm $j$'s demand, since that of firm $i$'s can be directly obtained as $D_i^k(p_i, p_j) = 1 - D_j^k(p_i, p_j)$.

**Case (iii)** In the *misaligned* case with *hedonic dominance* (i.e. for $\gamma > -\varepsilon e/q$, with $q > 0$ and $e < 0$) firm $j$'s demand is[25]

$$D_j^I(p_i, p_j) = 1 + \frac{\left(p_j - p_i + q\gamma\right)^2}{2q\gamma e\varepsilon} \text{ for } p_j \in [p_i - \gamma q, p_i - \varepsilon e - q\gamma] \tag{1.24}$$

in region $I$,

$$D_j^{II}(p_i, p_j) = \frac{2\left(p_i - p_j\right) - \varepsilon e}{2\gamma q} \text{ for } p_j \in [p_i - \varepsilon e - q\gamma, p_i]$$

in region $II$ and

$$D_j^{III}(p_i, p_j) = -\frac{\left(p_i - p_j - \varepsilon e\right)^2}{2\gamma q\varepsilon e} \text{ for } p_j \in [p_i, p_j - \varepsilon e] \tag{1.25}$$

in region $III$, respectively.

**Case (iv).** In the *misaligned* case with *environmental dominance* (i.e., for $\varepsilon > -q\gamma/e$ with $q < 0$ and $e > 0$), firms' demands in region $I$ and $III$ are invariant to the attribute dominance, thus remaining exactly as in (1.24)-(1.25) with modified ranges: $p_i \in [p_j + q\gamma, p_j]$ and $p_j \in [p_i, p_i - q\gamma]$ in region $I$ and $p_i \in [p_j + \varepsilon e - q\gamma, p_j + \varepsilon e]$ and $p_j \in [p_i - \varepsilon e, p_i + q\gamma - \varepsilon e]$ in region $III$. In contrast, in region $II$ the dominance of goods matters and firm $j$'s demand is

$$D_j^{II}(p_i, p_j) = \frac{2\left(p_i - p_j\right) - \gamma q}{2\varepsilon e} \text{ for } p_j \in [p_i - \varepsilon e - q\gamma, p_i]. \tag{1.26}$$

[24]Notice that the case with $e < 0$ and $q < 0$ is specular to the case discussed here. It can simply be obtained by permuting players $i$ and $j$.

[25]The case with $e > 0$ and $q < 0$ can be obtained by permuting players $i$ and $j$.

**Case (v).** In the *weakly (mis-)aligned* case with *environmental dominance* (i.e., for $\varepsilon e > 0$ and $q = 0$), firm $j$'s demand is:

$$D_j(p_i, p_j) = \frac{p_i - p_j}{\varepsilon e} \text{ for } p_j \in [p_i - \varepsilon e, p_i]. \tag{1.27}$$

**Case (vi).** In the *weakly (mis-)aligned* case with *hedonic dominance* (i.e., for $\gamma q > 0$ and $e = 0$), firm $j$'s demand is:

$$D_j(p_i, p_j) = \frac{p_i - p_j}{\gamma q} \text{ for } p_j \in [p_i - \gamma q, p_i]. \tag{1.28}$$

### 1.6.2 The Price Stage

Our aim here is to characterize the existence of interior Nash equilibrium prices in all price regions $I$, $II$, $III$. To accomplish this task, we use the demands (characterized above in Appendix 1) and derive from the FOCs for a profit maximum of each firm the candidate Nash equilibrium prices and, hence, check whether such prices are actually *feasible*, i.e., they belong to the price interval specific for the indicated region. Additionally, in each case, we check for the strict concavity of each firm's profit function with respect to its own price to ensure that the second-order conditions for a maximum hold. We conduct this analysis below in the proofs of Lemma 1-3.

#### Proof of Lemma 1

**(i)** Starting with the *aligned* case under *environmental dominance* (i.e. for $\varepsilon > q\gamma/e$ with $q > 0$ and $e > 0$),[26] firms' prices in region $I$ belong to the interval $p_i \in [p_j, p_j + q\gamma]$ and $p_j \in [p_i - q\gamma, p_i]$ and the system of FOCs for the two firms yields the following two candidate Nash equilibrium prices:

$$p_i^* = \frac{3}{4}\sqrt{2q\gamma e\varepsilon} \text{ and } p_j^* = \frac{1}{4}\sqrt{2q\gamma e\varepsilon}. \tag{1.29}$$

Second order conditions are also satisfied for both firms, since

$$\frac{\partial^2 \Pi_j(p_i, p_j)}{\partial p_j^2} = -\frac{2p_i - 3p_j}{q\gamma e\varepsilon} < 0 \tag{1.30}$$

and

$$\frac{\partial^2 \Pi_i(p_i, p_j)}{\partial p_i^2} = -\frac{3p_i - 2p_j}{q\gamma e\varepsilon} < 0 \tag{1.31}$$

hold, since from (1.29) it directly follows that $p_i^* > 2p_j^*/3$ and $p_j^* < 2p_i^*/3$. To check that the prices in (1.29) are the interior Nash equilibrium prices, it remains to verify that they belong to the appropriate price intervals, that here are

$$p_j^* + q\gamma > p_i^* > p_j^* \;\Rightarrow\; q\gamma > p_i^* - p_j^* > 0. \tag{1.32}$$

Plugging-in (1.29) into (1.32), it is obtained that

$$q\gamma > \frac{1}{2}\sqrt{2q\gamma e\varepsilon} > 0, \tag{1.33}$$

[26] Once again, the specular case with $e < 0$ and $q < 0$ can be obtained by permuting firms $i$ and $j$.

which, after some straightforward manipulation, yields

$$2q\gamma > e\varepsilon > 0,$$

a condition always holding under *environmental dominance*. Thus, this ensures that the candidate equilibrium prices obtained in (1.29) are actually interior Nash equilibrium prices.

**(ii)** Consider now the *aligned* case under *hedonic dominance* ($\gamma > e\varepsilon/q$ and $q > 0$ with $e > 0$). We remind here that in region $I$ (and $III$) firms' demands are invariant to the type of good *dominance* and, therefore, they are exactly as the demands defined in (1.6) with price ranges: $p_i \in [p_j, p_j + \varepsilon e]$ and $p_j \in [p_i - \varepsilon e, p_i]$. Thus, also the candidate equilibrium prices obtained from the FOCs are the same as in (1.29) and the second-order conditions for a maximum similarly hold. Hence, if we exclude the case for $p_i = p_j$, where only one firm (firm $i$) sells its product, inside the price range of region $I$ the following condition is needed:

$$p_j^* + \ \varepsilon e > p_i^* > p_j^* \ \Rightarrow \ \varepsilon e > p_i^* - p_j^* > 0.$$

which, using the prices in (1.29) becomes

$$\varepsilon e > \frac{1}{2}\sqrt{2q\gamma e\varepsilon} > 0,$$

which after a few straightforward manipulations yields

$$2\varepsilon e > q\gamma > 0,$$

always holding under *hedonic dominance*. Therefore, also under *aligned attributes* and *hedonic dominance* the prices in (1.29) are interior Nash equilibrium prices for region $I$. This completes part (i) and (ii) of the proof of Lemma 1.
We now complete the proof of Lemma 1 by showing that in *aligned case* with either environmental or hedonic dominance a Nash equilibrium never occurs in regions $II$ and $III$.

**(iii)** The price range of region $II$ for the *aligned* case with *environmental dominance* ($\varepsilon > q\gamma/e$ with $q > 0$ and $e > 0$) is $p_i \in [p_j + q\gamma, p_j + \varepsilon e]$ and $p_j \in [p_i - \varepsilon e, p_i - q\gamma]$ and the candidate Nash equilibrium prices obtained from the FOCs are, therefore:

$$p_i^* = \frac{1}{6}\left(4e\varepsilon + q\gamma\right) \text{ and } p_j^* = \frac{1}{6}\left(2e\varepsilon - q\gamma\right). \tag{1.34}$$

Second order conditions are satisfied for both firms, since

$$\frac{\partial^2 \Pi_j(p_i, p_j)}{\partial p_j^2} = \frac{\partial^2 \Pi_i\left(p_i, p_j\right)}{\partial p_i^2} = -\frac{2}{e\varepsilon} < 0.$$

To check whether the prices in (1.34) are an interior Nash equilibrium, we have to verify whether they belong to the appropriate price interval, which for region $II$ is

$$p_j^* + \varepsilon e > p_i^* > p_j^* + q\gamma \ \Rightarrow \varepsilon e > p_i^* - p_j^* > q\gamma. \tag{1.35}$$

Plugging-in (1.34) into (1.35), we obtain:

$$\varepsilon e > \frac{1}{3}\left(e\varepsilon + q\gamma\right) > q\gamma, \tag{1.36}$$

which violates *environmental dominance*. Therefore, this fact proves that a Nash equilibrium price can never occur under *aligned attributes* and *environmental dominance*. In particular, the required condition in (1.36) is $\varepsilon > 2q\gamma/e$.

**(iv)** We now turn to the price range for region $II$ in the *aligned* case with *hedonic dominance* (i.e. for $\gamma > e\varepsilon/q$ and $q > 0$ with $e > 0$), with price range $p_i \in [p_j + \varepsilon e, p_j + q\gamma]$ and $p_j \in [p_i - q\gamma, p_i - e\varepsilon]$. Here the obtained candidate Nash equilibrium prices are:

$$p_i^* = \frac{1}{6}\left(4q\gamma + e\varepsilon\right) \text{ and } p_j^* = \frac{1}{6}\left(2q\gamma - e\varepsilon\right). \tag{1.37}$$

Second order conditions are satisfied for both firms, since

$$\frac{\partial^2 \Pi_j(p_i,p_j)}{\partial p_j^2} = \frac{\partial^2 \Pi_i\left(p_i,p_j\right)}{\partial p_i^2} = -\frac{2}{q\gamma} < 0.$$

To check whether the prices in (1.37) are an interior Nash equilibrium, we have now to verify whether they belong to the appropriate price interval, which for this case is

$$p_j^* + q\gamma > p_i^* > p_j^* + \varepsilon e \;\Rightarrow\; q\gamma > p_i^* - p_j^* > \varepsilon e. \tag{1.38}$$

Plugging-in (1.37) into (1.38), we obtain

$$q\gamma > \frac{1}{3}\left(e\varepsilon + q\gamma\right) > \varepsilon e. \tag{1.39}$$

that, however, violates *hedonic dominance*. Hence, also in this case a Nash equilibrium price can never occurs under *hedonic dominance*. In particular, the condition in (1.39) requires $\gamma > 2e\varepsilon/q$.

We conclude by checking the case for region $III$. In the *aligned* case under *environmental dominance* (i.e. for $\varepsilon > q\gamma/e$ with $q > 0$ and $e > 0$), the price interval for region $III$ is $p_i \in [p_j + \varepsilon e, p_j + q\gamma + \varepsilon e]$ and $p_j \in [p_i - q\gamma - \varepsilon e, p_i - \varepsilon e]$. In this case the FOCs for a profit maximum of both firms yield the following two candidate Nash equilibrium prices:

$$p_i^* = \frac{1}{8}\left(\sqrt{e^2\varepsilon^2 + q^2\gamma^2 + 10q\gamma\varepsilon e} + e\varepsilon + q\gamma\right), \tag{1.40}$$

$$p_j^* = \frac{1}{8}\left(3\sqrt{e^2\varepsilon^2 + q^2\gamma^2 + 10q\gamma e\varepsilon} - 5\left(\varepsilon e + q\gamma\right)\right). \tag{1.41}$$

Second order conditions are satisfied for both firms, since

$$\frac{\partial^2 \Pi_j(p_i,p_j)}{\partial p_j^2} = \frac{2p_i - 3p_j - 2\left(e\varepsilon + q\gamma\right)}{\varepsilon e q\gamma} < 0$$
$$\frac{\partial^2 \Pi_i\left(p_i,p_j\right)}{\partial p_i^2} = \frac{3p_i - 2p_j - 2\left(e\varepsilon + q\gamma\right)}{\varepsilon e q\gamma} < 0,$$

hold for $p_i^* < \left(2p_j^* + 2\left(e\varepsilon + q\gamma\right)\right)/3$ and $p_j^* > \left(2p_i^* - 2\left(e\varepsilon + q\gamma\right)\right)/3$ which, using (1.40) and (1.41) are always satisfied. To check whether these prices constitute an interior Nash equilibrium, we can again verify whether they are feasible in the appropriate price intervals for region $III$:

$$p_j^* + q\gamma + \varepsilon e > p_i^* > p_j^* + \varepsilon e \;\Rightarrow\; \gamma q + \varepsilon e > p_i^* - p_j^* > \varepsilon e. \tag{1.42}$$

Thus, plugging-in (1.40)-(1.41) into (1.42), we obtain

$$\gamma q + \varepsilon e > \frac{1}{4}\left(3\left(\varepsilon e + \gamma q\right) - \sqrt{\varepsilon^2 e^2 + \gamma^2 q^2 + 10\gamma q \varepsilon e}\right) > \varepsilon e,$$

that, after a few straightforward manipulations of the above right-hand inequality requires $\varepsilon < q\gamma/\left(2e\right)$ to hold, a condition violating *environmental dominance*. Therefore, for the case of aligned attribute and *environmental dominance* an interior Nash equilibrium price can never occur in region $III$.

Finally, under aligned attributes and *hedonic dominance* (i.e. for $\gamma > e\varepsilon/q$ and $q > 0$ with $e > 0$) the candidate Nash equilibrium prices for region $III$ are the same as in (1.40)-(1.41) although in a different price range, i.e., $p_i \in [p_j + q\gamma, p_j + q\gamma + \varepsilon e]$ and $p_j \in [p_i - q\gamma - e\varepsilon, p_i - q\gamma]$. We have to verify that the candidate Nash equilibrium prices belong to the intervals

$$p_j^* + q\gamma + \varepsilon e > p_i^* > p_j^* + q\gamma \;\Rightarrow\; \gamma q + \varepsilon e > p_i^* - p_j^* > \gamma q, \tag{1.43}$$

that, plugging-in (1.40)-(1.41) into (1.43), yields

$$\gamma q + \varepsilon e > \frac{1}{4}\left(3\left(\varepsilon e + \gamma q\right) - \sqrt{\varepsilon^2 e^2 + \gamma^2 q^2 + 10\gamma q \varepsilon e}\right) > \gamma q,$$

which requires $e\varepsilon > 2q\gamma$ to hold, a condition never occurring under *hedonic dominance*. Thus, also in the case of aligned attributes and *hedonic dominance* a Nash equilibrium price can never occurs for region $III$. This completes the proof of Lemma 1.

So far we have proved that, under *aligned attributes* an interior equilibrium for region $I$ can only occur under *environmental or hedonic dominance*. In contrast, we proved above that in region $II$ an interior Nash equilibrium can only occur under $\varepsilon > 2\frac{q}{e}\gamma$ (resp. $\gamma > 2\frac{e}{q}\varepsilon$). We proved that an interior Nash equilibrium in region $III$ never occurs.

### Proof of Lemma 2

Repeating now the procedure followed above for the case of aligned attributes, we consider now the case of *misaligned attributes*. We begin with the *misaligned* case under *hedonic dominance* (i.e. for $\gamma > -e\varepsilon/q$ with $q > 0$ and $e < 0$), reminding that in this case the price range for region $I$ is given by $p_i \in [p_j + \gamma q + \varepsilon e, p_j + \gamma q]$ and $p_j \in [p_i - \gamma q, p_i - \varepsilon e - q\gamma]$, respectively. In such a case the following two candidate Nash equilibrium prices arise

$$p_i^* = \frac{1}{8}\left(\sqrt{\gamma q\left(-8\varepsilon e + \gamma q\right)} + \gamma q\right) \text{ and } p_j^* = \frac{1}{8}\left(3\sqrt{\gamma q\left(-8\varepsilon e + \gamma q\right)} - 5\gamma q\right). \tag{1.44}$$

Second-order conditions hold, since at equilibrium $\frac{2}{3}p_i^* - \frac{2}{3}\gamma q < p_j^*$ and $\frac{2}{3}\gamma q + \frac{2}{3}p_j^* > p_i^*$. Thus, for the equilibrium prices to belong to region $I$, we need that

$$-\varepsilon e - \gamma q > \frac{1}{4}\left(\sqrt{\gamma q\left(-8\varepsilon e + \gamma q\right)} - 3q\gamma\right) > -\gamma q.$$

Notice that the left-hand side inequality holds if and only if $\varepsilon > -q\gamma/e$, which contradicts the definition of *hedonic dominance*. Therefore, under *misaligned attributes* and *hedonic dominance*, an interior Nash equilibrium can never occur in region $I$.

Now, for the *misaligned* case under *environmental dominance* (i.e. for $\varepsilon > -q\gamma/e$ with $q < 0$ and $e > 0$), the demands and prices in equilibrium are exactly as before, although in the price ranges: $p_i \in [p_j + q\gamma, p_j]$ and $p_j \in [p_i, p_i - q\gamma]$. Thus, for this case, the candidate Nash equilibrium prices (44) respect the price range of region $I$ for

$$p_j^* > p_i^* > p_j^* + q\gamma \ \Rightarrow 0 > p_i^* - p_j^* > q\gamma,$$

which using (44) becomes

$$0 > \frac{1}{4}\left(\sqrt{q\gamma\left(-8\varepsilon e + \gamma q\right)} + 3q\gamma\right) > q\gamma.$$

which, again, is never satisfied since $0 > p_i^* - p_j^*$ needs $\gamma > -e\varepsilon/q$ that, in turn, contradicts *environmental dominance*. Therefore, prices in (44) cannot be interior Nash equilibrium prices.

We move now to region $II$ for the *misaligned* case under *hedonic dominance* (i.e. for $\gamma > -e\varepsilon/q$ and $q > 0$ with $e < 0$) where the price range is $p_i \in [p_j, p_j + \gamma q + \varepsilon e]$ and $p_j \in [p_i - \varepsilon e - q\gamma, p_i]$, and the candidate Nash equilibrium prices are:

$$p_i^* = \frac{4\gamma q + \varepsilon e}{6} \text{ and } p_j^* = \frac{2\gamma q - \varepsilon e}{6}$$

Second-order conditions hold since $q > 0$. Thus the candidate Nash equilibrium prices respect the price range for

$$0 > \frac{-\varepsilon e - q\gamma}{3} > -\varepsilon e - q\gamma$$

where the two inequalities above are always verified under $\gamma > -e\varepsilon/q$, i.e. the condition of *hedonic dominance*. Therefore, this fact proves that an interior Nash equilibrium price can occur under *misaligned attributes* and *hedonic dominance* in region $II$.

We can now consider the *misaligned* case with *environmental dominance* ($\varepsilon > -q\gamma/e$ with $q < 0$ and $e > 0$) where the price ranges for region $II$ are $p_i \in [p_j, p_j + \varepsilon e + q\gamma]$ and $p_j \in [p_i - \varepsilon e - q\gamma, p_i]$ and the candidate equilibrium prices are:

$$p_i^* = \frac{1}{6}\left(4e\varepsilon + q\gamma\right) \text{ and } p_j^* = \frac{1}{6}\left(2e\varepsilon - q\gamma\right). \tag{1.45}$$

Second-order conditions are always satisfied for both firms, since

$$\frac{\partial^2 \Pi_j(p_i, p_j)}{\partial p_j^2} = \frac{\partial^2 \Pi_i\left(p_i, p_j\right)}{\partial p_i^2} = -\frac{2}{e\varepsilon} < 0.$$

To check whether the prices in (1.45) are interior Nash equilibrium, we have to verify whether they belong to the appropriate price interval, which for region $II$ is

$$p_j^* + \varepsilon e + q\gamma > p_i^* > p_j^* \ \Rightarrow e\varepsilon + q\gamma > p_i^* - p_j^* > 0. \tag{1.46}$$

Plugging-in (1.45) into (1.46), we obtain:

$$e\varepsilon + q\gamma > \frac{1}{3}\left(e\varepsilon + q\gamma\right) > 0,$$

where the two inequalities above are always verified under $\varepsilon > -q\gamma/e$, i.e. the condition of *environmental dominance.* Therefore, this fact proves that an interior Nash equilibrium price can occur under *misaligned attributes* and *environmental dominance* in region $II$.

We consider the case of misaligned attributes and *hedonic dominance* (i.e. for $\gamma > -e\varepsilon/q$ with $q > 0$ and $e < 0$) for region $III$, with price intervals of $p_i \in [p_j + \varepsilon e, p_j]$ and $p_j \in [p_i, p_i - \varepsilon e]$ and the candidate Nash equilibrium prices are:

$$p_i^* = \frac{1}{8}\left(12\sqrt{-\frac{1}{16}\varepsilon e\left(8q\gamma - \varepsilon e\right)} + 5e\varepsilon\right), \tag{1.47}$$

and

$$p_j^* = \frac{1}{8}\left(4\sqrt{-\frac{1}{16}\varepsilon e\left(8q\gamma - \varepsilon e\right)} - \varepsilon e\right). \tag{1.48}$$

Second-order conditions are satisfied for both firms also in this case, since $p_i^* > \frac{3}{2}p_j^* + \varepsilon e$ and $p_j^* < \frac{3}{2}p_i^* - \varepsilon e$. To check whether these prices are an interior Nash equilibrium, we verify whether they are compatible with the appropriate price intervals of region $III$, yielding:

$$-\varepsilon e > \frac{1}{4}\left(-3\varepsilon e - 4\sqrt{-\frac{1}{16}\varepsilon e\left(-\varepsilon e + 8q\gamma\right)}\right) > 0$$

that implies $\varepsilon > -q\gamma/e$, a condition violating *hedonic dominance.* Therefore, in the case of misaligned attribute and *hedonic dominance* a Nash equilibrium price can never occur in region $III$.

Finally in the case of misaligned attributes and *environmental dominance* ($\varepsilon > -q\gamma/e$ with $q < 0$ and $e > 0$) for region $III$ with price ranges $p_i \in [p_j + \varepsilon e + q\gamma, p_j + \varepsilon e]$ and $p_j \in [p_i - \varepsilon e, p_i - q\gamma - \varepsilon e]$. We need to check that:

$$-\varepsilon e > \frac{1}{4}\left(-3\varepsilon e - 4\sqrt{-\frac{1}{16}\varepsilon e\left(-\varepsilon e + 8q\gamma\right)}\right) > -\varepsilon e - q\gamma,$$

which, again, requires $\gamma > -e\varepsilon/q$ to hold, a condition violating *environmental dominance.* This completes the proof of Lemma 2.

### Proof of Lemma 3

We consider now the case of *weakly (mis)aligned attributes.* We focus on the case with either $q > 0$ and $e_i = e_j$, or, alternatively, $e > 0$ and $q_i = q_j$. In this case, using the demand functions (**v**) and (**vi**) presented above in Appendix 1, the price range when $q_i > q_j$ and $e_i = e_j$ is given by $p_i \in [p_j, p_j + \gamma q]$ and $p_j \in [p_i - \gamma q, p_i]$, respectively. The following two candidate Nash equilibrium prices arise from the solution of FOCs for a maximum:

$$p_i^* = \frac{2}{3}\gamma q \text{ and } p_j^* = \frac{1}{3}\gamma q$$

Second order conditions always hold for $q > 0$. Thus, the candidate Nash equilibrium prices respect the price range for

$$\gamma q > \frac{1}{3}\gamma q > 0$$

where the two inequalities above are always verified under $\gamma q > 0$. Therefore, an interior Nash equilibrium price occurs under *weakly (mis)aligned attributes* and *hedonic dominance*.

When, instead, $q_i = q_j$ and $e_i > e_j$ the price range is given by $p_i \in [p_j, p_j + \varepsilon e]$ and $p_j \in [p_i - \varepsilon e, p_i]$. The following two candidate Nash equilibrium prices arise from the FOCs for a maximum:

$$p_i^* = \frac{2}{3}\varepsilon e \text{ and } p_j^* = \frac{1}{3}\varepsilon e$$

Second order conditions always hold for $e > 0$. Thus, the candidate Nash equilibrium prices respect the price range

$$\varepsilon e > \frac{1}{3}\varepsilon e > 0$$

where the two inequalities above are always verified under $\varepsilon e > 0$. Therefore, an interior Nash equilibrium price occurs under *weakly (mis)aligned attributes* and *environmental dominance*. This completes the proof of Lemma 3.

### 1.6.3 The Quality Stage

In this appendix, given the equilibrium prices studied above in Appendix 2, we ascertain the existence of Nash equilibrium qualities for both firms. The methodology is standard (see Vandenbosch and Weinberg [1995]) and consists of computing the optimal qualities in each feasible price region and then comparing the obtained profit levels across regions to find the quality levels that yield the maximum profits.

#### Aligned case

Starting with the *aligned* case under *environmental dominance* (i.e., for $\varepsilon > q\gamma/e$ with $q > 0$ and $e > 0$), it is easy to see that condition $\varepsilon \in [q\gamma/e, 2q\gamma/e]$ ensures that firms' prices are in region $I$. Thus, we obtain the following quality-stage profits function for firm $i = 1, 2$ and $j \neq i$:

$$\Pi_i(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{9}{16}\sqrt{2e\varepsilon q\gamma} \text{ and } \Pi_j(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{1}{16}\sqrt{2e\varepsilon q\gamma}. \tag{1.49}$$

From the above expressions, it is immediate to see that the partial derivatives of each firm profit function with respect to its own qualities are monotone, yielding the following corner solutions:

$$q_i^* = q_{\max},\ q_j^* = q_{\min} \tag{1.50}$$

and

$$e_i^* = e_{\max},\ e_j^* = e_{\min}. \tag{1.51}$$

Candidate firm equilibrium profits for this price region are, respectively, $\Pi_i^e = 9\sqrt{2\hat{e}\varepsilon\hat{q}\gamma}/16$ and $\Pi_j^e = \sqrt{2\hat{e}\varepsilon\hat{q}\gamma}/16$ for $\varepsilon \in [\hat{q}\gamma/\hat{e}, 2\hat{q}\gamma/\hat{e}]$.

Since in region $I$ firms' profits are invariant to the type of good *dominance*, under *hedonic dominance* they will be exactly as in (1.49) for a different price range. As a result, under *hedonic dominance* (i.e., for $\gamma > e\varepsilon/q$ with $q > 0$ and $e > 0$), the condition $\gamma \in [e\varepsilon/q, 2e\varepsilon/q]$ ensures that firms' prices are in region $I$. Similarly to what shown above, the candidate equilibrium qualities are the same as in (1.50)-(1.51) for $\varepsilon \in [\hat{q}\gamma/(2\hat{e}), 2\hat{q}\gamma/\hat{e}]$.

The price range of region $II$ for the *aligned* case under *environmental dominance* ($\varepsilon > q\gamma/e$ with $q > 0$ and $e > 0$) is satisfied for $\varepsilon \in [2q\gamma/e, \infty)$. First stage profits are

$$\Pi_i(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{(4e\varepsilon + q\gamma)^2}{36e\varepsilon} \text{ and } \Pi_j(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{(2e\varepsilon - q\gamma)^2}{36e\varepsilon}.$$

Analogously to what performed above, the study of profits' partial derivates with respect to qualities yields: $q_i^* = q_j^* = q_{\max}$ whereas $e_i^* = e_{\max}$ and $e_j^* = e_{\min}$. Firms' profits are $\Pi_i^e = 4\hat{e}\varepsilon/9$ and $\Pi_j^e = \varepsilon\hat{e}/9$ for any $\varepsilon \in (0, \infty)$. In the case of *hedonic dominance* we have

$$\Pi_i(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{(e\varepsilon + 4q\gamma)^2}{36q\gamma} \text{ and } \Pi_j(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{(2q\gamma - e\varepsilon)^2}{36q\gamma},$$

that yields $q_i^* = q_{\max}$, $q_j^* = q_{\min}$ and $e_i^* = e_j^* = e_{\max}$. For this case, candidate profits are $\Pi_i^h = \frac{4}{9}\hat{q}\gamma$ and $\Pi_j^h = \frac{1}{9}\hat{q}\gamma$ for any $\gamma \in (0, \infty)$.

### Misaligned case

We now turn to the *misaligned case* with *environmental dominance* (i.e. $\varepsilon > -q\gamma/e$ with $q < 0$ and $e > 0$), the condition $\varepsilon \in [-q\gamma/e, \infty)$ ensures that firms' prices are in the range $II$. Then, we obtain the following firms' profits:

$$\Pi_i(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{(4e\varepsilon + q\gamma)^2}{36e\varepsilon} \text{ and } \Pi_j(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{(2e\varepsilon - q\gamma)^2}{36e\varepsilon}$$

The study of partial derivatives of profit functions with respect to qualities yields: $q_i^* = q_j^* = q_{\max}$ whereas $e_i^* = e_{\max}$ and $e_j^* = e_{\min}$. Firms' candidate equilibrium profits are $\Pi_i^e = 4\hat{e}\varepsilon/9$ and $\Pi_j^e = \varepsilon\hat{e}/9$ for any $\varepsilon \in (0, \infty)$. Notice that the profits in this case are exactly equal to those obtained in the *aligned case* with *environmental dominance* for price region $II$. Under *hedonic dominance* (i.e. $\varepsilon > -q\gamma/e$ with $q > 0$ and $e < 0$) it holds

$$\Pi_i(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{(e\varepsilon + 4q\gamma)^2}{-36q\gamma} \text{ and } \Pi_j(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{(e\varepsilon - 2q\gamma)^2}{-36q\gamma},$$

that yields $q_j^* = q_{\min}$ and $q_i^* = q_{\max}$ whereas $e_i^* = e_j^* = e_{\max}$. Then firms profits are $\Pi_i^h = 4\hat{q}\gamma/9$ and $\Pi_j^h = \hat{q}\gamma/9$ for any $\gamma \in (0, \infty)$. Consider now the *misaligned case* with *environmental dominance* (i.e. $\varepsilon > -q\gamma/e$ with $q < 0$ and $e > 0$). The condition $\varepsilon \in [-q\gamma/e, \infty)$ assures that firms' prices are in the price range $II$. Firms' profits are:

$$\Pi_i(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{(-4\varepsilon e - \gamma q)^2}{-36\varepsilon e} \text{ and } \Pi_j(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{(\gamma q - 2\varepsilon e)^2}{-36\varepsilon e}.$$

the study of profits' partial derivates with respect to qualities yields: $q_1^* = q_2^* = q_{\max}$ whereas $e_j^* = e_{\min}$ and $e_i^* = e_{\max}$. Candidate equilibrium firms' profits are $\Pi_i^e = 4\hat{e}\varepsilon/9$ and $\Pi_j^e = \varepsilon\hat{e}/9$ for any $\varepsilon \in (0, \infty)$. Finally, under *hedonic dominance* (i.e. $\varepsilon > -q\gamma/e$ with $q > 0$ and $e < 0$) firms' profits are

$$\Pi_i(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{(4\gamma q + \varepsilon e)^2}{36\gamma q} \text{ and } \Pi_j(p_i^*(\mathbf{e},\mathbf{q}), p_j^*(\mathbf{e},\mathbf{q})) = \frac{(2\gamma q - \varepsilon e)^2}{36\gamma q},$$

and we obtain $q_i^* = q_{\max}$ and $q_j^* = q_{\min}$ whereas $e_i^* = e_j^* = e_{\max}$. Candidate equilibrium firms' profits are $\Pi_i^h = 4\hat{q}\gamma/9$ and $\Pi_j^h = \hat{q}\gamma/9$ for any $\gamma \in (0, \infty)$.

**Weak (Mis)Alignment case**

Consider now the result of Appendix 2, Lemma 3. We have shown that prices depend only on both, the dominant social driver, and the relevant quality. Moreover, firms' market shares are constant. The partial derivatives of each firm profit function with respect to its own qualities are monotone. Thus, it follows that the only possible equilibrium profits are $\Pi_i^h = 4\hat{q}\gamma/9$ and $\Pi_j^h = \hat{q}\gamma/9$ for any $\gamma \in (0, \infty)$ under *hedonic dominance* and $\Pi_i^e = 4\hat{e}\varepsilon/9$ and $\Pi_j^e = \varepsilon\hat{e}/9$ for any $\varepsilon \in (0, \infty)$, under *environmental dominance.*

**Comparison**

We now compare firms' candidate maximum profits in each region to determine the firm's optimal quality choice. Considering the candidate equilibrium qualities, we divide the parameters space ($\varepsilon$, $\gamma$) into the following: (i) $0 < \varepsilon < \hat{q}\gamma/(2\hat{e})$, (ii) $\hat{q}\gamma/(2\hat{e}) < \varepsilon < \hat{q}\gamma/\hat{e}$, (iii) $\hat{q}\gamma/\hat{e} < \varepsilon < 2\hat{q}\gamma/\hat{e}$, and (iv) $2\hat{q}\gamma/\hat{e} < \varepsilon < \infty$.
Regions (i) and (ii) characterize *hedonic dominance*, whereas (iii) and (iv) *environmental dominance.*

(i) When $0 < \varepsilon < \hat{q}\gamma/(2\hat{e})$, the only candidate equilibrium profits are those in pricing region $II$ for both *goods alignment*, *misalignment*, or *weak (mis-)alignment.* Firms can obtain these profit levels by choosing between minimum and maximum feasible levels for both qualities. The comparison of these candidates reveals that within case (i) the following ranking holds: $\Pi_i^h > \Pi_i^e$ i.e., $4\hat{q}\gamma/9 > 4\hat{e}\varepsilon/9$ and $\Pi_j^h > \Pi_j^e$ i.e., $\hat{q}\gamma/9 > \varepsilon\hat{e}/9$.
Then, the maximum profits are obtained for $e_i^* = e_j^* = e_{\max}$ whereas $q_i^* = q_{\max}$ and $q_j^* = q_{\min}$.

(ii) When $\hat{q}\gamma/(2\hat{e}) < \varepsilon < \hat{q}\gamma/\hat{e}$, firms can obtain regions $I$ and $II$ profit levels by choosing between different quality levels. However, the comparison reveals that profits in region $II$ always dominate those of region $I$. Considering the quality choice, when a firm chooses the maximum feasible level for each quality, the best response for the rival is always to set the maximum for hedonic and the minumum for environmental quality. This latter rival's strategy yields $\Pi_j^h = \hat{q}\gamma/9$, a profit level that always dominates the alternative, which yields $\Pi_j^h = \sqrt{2\hat{e}\varepsilon\hat{q}\gamma}/16$, a profit level obtained when setting both qualities at the minimum feasible.[27]
Then, the maximum profits are again obtained for $e_i^* = e_j^* = e_{\max}$ whereas $q_i^* = q_{\max}$ and $q_j^* = q_{\min}$.

Hence, the comparisons in (i) and (ii) reveal that under *hedonic dominance* setting $e_i^* = e_j^* = e_{\max}$ and $q_i^* = q_{\max}$ with $q_j^* = q_{\min}$, yield the highest profits levels for both firms.

[27] The condition that satisfies the inequality $\hat{q}\gamma/9 > \sqrt{2\hat{e}\varepsilon\hat{q}\gamma}/16$ is $\varepsilon < (128\hat{q}\gamma)\,/\,(81\hat{e})$ which always holds in case (ii), i.e. $\hat{q}\gamma/(2\hat{e}) < \varepsilon < \hat{q}\gamma/\hat{e}$.

We now move to (iii) and (iv), the cases representing *environmental dominance*.

(iii) When $\hat{q}\gamma/\hat{e} < \varepsilon < 2\hat{q}\gamma/\hat{e}$, firms can obtain region $I$ and $II$ profits levels. Here the same rationale of point (ii) applies. In this case the ranking is $\Pi_i^e > \Pi_i^h$ i.e., $4\hat{e}\varepsilon/9 > 4\hat{q}\gamma/9$ and $\Pi_j^e > \Pi_j^h$ i.e., $\varepsilon\hat{e}/9 > \hat{q}\gamma/9$. Moreover, rival's profits in the region $I$, i.e., $\Pi_j^e = \sqrt{2\hat{e}\varepsilon\hat{q}\gamma}/16$, are always dominated by those of region $II$, i.e., $\Pi_j^e = \hat{e}\varepsilon/9$.[28]
Then, the maximum profits are obtained for $q_i^* = q_j^* = q_{\max}$ and $e_i^* = e_{\max}$ with $e_j^* = e_{\min}$.

(iv) When $2\hat{q}\gamma/\hat{e} < \varepsilon < \infty$, the same rationale of point (i) applies, i.e., the only candidate profits are those of the pricing region $II$. Thus, we have $4\hat{e}\varepsilon/9 > 4\hat{q}\gamma/9$ and $\varepsilon\hat{e}/9 > \hat{q}\gamma/9$.
Then, the maximum profits are obtained for $q_i^* = q_j^* = q_{\max}$ and $e_i^* = e_{\max}$ with $e_j^* = e_{\min}$.

The cases (iii) and (iv) reveal that under *environmental dominance* setting $q_i^* = q_j^* = q_{\max}$ and $e_i^* = e_{\max}$ with $e_j^* = e_{\min}$, yield the highest profits levels for both firms.

We conclude that the choice of the equilibrium qualities is independent of good *alignment* or *misalignment*, as firms always choose to differentiate their good *only along one attribute*. Thus, the only endogenous configuration is *weak (mis-)alignment*, or equally, a *Max-Min* quality configuration. What matters is the relative strength of the social drivers that switch the firms' optimal strategy. We can resume the quality choice presented above as follows:

If $\varepsilon \geq \hat{q}\gamma/\hat{e}$, then $e_i^* = e_{\max}$ with $e_j^* = e_{\min}$ and $q_j^* = q_i^* = q_{\max}$,
If $\varepsilon \leq \hat{q}\gamma/\hat{e}$, then $q_i^* = q_{\max}$ with $q_j^* = q_{\min}$ and $e_i^* = e_j^* = e_{\max}$.

The case of $\varepsilon = \hat{q}\gamma/\hat{e}$ shows a market outcome depending only on one quality gap and social driver, which can be either of the two as they are equal.

As explained in the quality stage section, firms decide to differentiate along the specific quality affected by the dominant social driver, which boosts their profitability.

This concludes the proof of the quality stage.

### 1.6.4 The Effects of Social Drivers on Welfare

We start by proving Proposition 4. Recall that under *environmental dominance*, the Nash equilibrium prices are $p_i^* = 2\hat{e}\varepsilon/3$ and $p_j^* = \hat{e}\varepsilon/3$, whereas the indifferent consumer is $\theta_\varepsilon = 1/3$.
We obtain the consumer surplus by plugging equilibrium prices in the utility levels:

$$CS^e = \int_0^1 \left( \int_0^{\theta_\varepsilon} (U_j)\, \mathrm{d}\theta_\varepsilon \right) \mathrm{d}\theta_\gamma + \int_0^1 \left( \int_{\theta_\varepsilon}^1 (U_i)\, \mathrm{d}\theta_\varepsilon \right) \mathrm{d}\theta_\gamma .$$

(**i**) The environmentalism effect is

$$\frac{\partial CS^e(\mathbf{e}^*, \mathbf{q}^*)}{\partial \varepsilon} = -\left(2e_{\max} - 11e_{\min}\right) / \left(18\right) \lesseqgtr 0,$$

and depends on the gap between the maximum and minimum feasible environmental quality levels. When $e_{\max} > 11e_{\min}/2$, the effect on consumer surplus is negative.

**(ii)** Anti-hedonism always lowers consumers surplus as it decreases the evaluation of the hedonic quality. Formally, the effect is $-\partial CS^e(\mathbf{e}^*, \mathbf{q}^*)/\partial\gamma = -q_{\max}/2$.

[28]The condition that satisfies the inequality $\hat{e}\varepsilon/9 > \sqrt{2\hat{e}\varepsilon\hat{q}\gamma}/16$ is $\varepsilon > (81\hat{q}\gamma)/(128\hat{e})$ which always holds in case (iii), i.e., $\hat{q}\gamma/\hat{e} < \varepsilon < 2\hat{q}\gamma/\hat{e}$.

Consider now Proposition 5. We recall that under *hedonic dominance*, the Nash equilibrium prices are $p_i^* = 2\gamma\hat{q}/3$ and $p_j^* = \gamma\hat{q}/3$, whereas the indifferent consumer is $\theta_\gamma = 1/3$.
We obtain the consumer surplus by plugging equilibrium prices in the utility levels:

$$CS^h(\mathbf{e}^*, \mathbf{q}^*) = \int_0^1 \left( \int_0^{\theta_\gamma} (U_j) \, \mathrm{d}\theta_\gamma \right) \mathrm{d}\theta_\varepsilon + \int_0^1 \left( \int_{\theta_\gamma}^1 (U_i) \, \mathrm{d}\theta_\gamma \right) \mathrm{d}\theta_\varepsilon.$$

(**i**) The anti-hedonism effect is

$$-\frac{\partial CS^h(\mathbf{e}^*, \mathbf{q}^*)}{\partial \gamma} = (2q_{\max} - 11q_{\min}) \, / \, (18) \gtreqless 0,$$

and depends on the gap between the maximum and minimum feasible hedonic quality levels. When $q_{\max} < 11q_{\min}/2$ the effect on consumer surplus is negative.
**(ii)** Environmentalism always benefits consumers surplus as it increases the environmental quality evaluation. Formally, the effect is $\partial CS^h(\mathbf{e}^*, \mathbf{q}^*)/\partial\varepsilon = e_{\max}/2$.

We now turn to social welfare in Proposition 6. This is obtained by aggregating consumers surplus, profits, and environmental surplus:

$$SW^* = CS^* + \Pi_1^* + \Pi_2^* + E^*.$$

(**i**) The effects of anti-hedonism and environmentalism under *environmental dominance* are equal to:

$$\frac{\partial SW^e(\mathbf{e}^*, \mathbf{q}^*)}{\partial \varepsilon} = \frac{8e_{\max} + e_{\min}}{18} \text{ and } -\frac{\partial SW^e(\mathbf{e}^*, \mathbf{q}^*)}{\partial \gamma} = -\frac{q_{\max}}{2},$$

whereas under *hedonic dominance*, these are:

$$\frac{\partial SW^h(\mathbf{e}^*, \mathbf{q}^*)}{\partial \varepsilon} = \frac{e_{\max}}{2} \text{ and } -\frac{\partial SW^h(\mathbf{e}^*, \mathbf{q}^*)}{\partial \gamma} = -\frac{8q_{\max} + q_{\min}}{18}.$$

From the above equations it is immediately seen that the effect of the dominated social driver is just to affect consumer surplus. For example, consider the case of *environmental dominance*. Formally, $-\left(\partial CS^e(\mathbf{e}^*, \mathbf{q}^*)/\partial\gamma\right) = -\left(\partial SW^e(\mathbf{e}^*, \mathbf{q}^*)/\partial\gamma\right)$ as there is no effect on firms' prices, profits, market shares, and environmental surplus. The same holds in the case of hedonic dominance.

This concludes the analysis of the results of Proposition 4, 5, and 6.

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# Chapter 2

# Anti-Consumerism: Stick or Carrot?

## 2.1 Introduction

Reducing worldwide emissions to counter climate change has recently become one of the most impellent humankind's challenges.[1] Such an ambitious objective calls for joint efforts from a broad range of stakeholders, including companies, governmental and nongovernmental organizations, but also citizens. Indeed, it is increasingly recognized that individuals, alongside with organizations, must be encouraged to limit their consumption levels to meet environmental goals.[2]

With this in mind, anti-consumerism (or anti-consumption) ideologies may serve as a backbone of environmental policies by leading citizens toward more sustainable consumption habits.[3] Simply put, anti-consumerism is a doctrine that combats excessive consumption for its perilous consequences. It is promoted by both private and public institutions and has many faces.[4]

On Black Friday in 2011, for instance, the popular clothing brand *Patagonia* launched its "Don't buy This Jacket" campaign arguing that:[5]

> *...to address the issue of consumerism [...] and lighten our environmental footprint, everyone needs to consume less.*

This message received widespread attention and acted as a public call to reduce consumption.[6] As another example, the European Commission recently kicked off the *ReSet the Trend* campaign to engage young Europeans in a battle against fast fashion. With an eye on stimulating sustainable clothing production, it stated:[7]

> *Fast fashion depletes our resources [...] let's make fast fashion out of fashion.*

[1]This chapter extends Bos et al. [2024]. I acknowledge Iwan Bos and Marco Marini's contributions.

[2]See, *e.g.*, Rogelj et al. [2015] and Millar et al. [2017].

[3]The term *consumerism* is attributed to John Bugas, the number two of Ford Motor Company, who introduced it in one of its public speeches in 1955. Since then, its antonym, *anti-consumerism*, has been used to indicate any ideology against the excessive consumption typical of mature capitalistic societies. Henceforth, we will use the terms *anti-consumerism* and *anti-consumption* interchangeably.

[4]As pointed out by Chatzidakis and Lee [2013] and Makri et al. [2020], a clear conceptualization of anti-consumption is currently missing and most studies view this phenomenon either as an individual attitude or lifestyle (*e.g.*, in Cherrier and Murray [2007] and Galvagno [2011], a motivation (*e.g.*, in Iyer and Muncy [2009], Lee et al. [2009a], Sandıkcı and Ekici [2009], Cherrier et al. [2011], and García-de Frutos et al. [2018]) or simply as a practice (*e.g.*, in Cherrier [2009]).

[5]See www.patagonia.com/stories/dont-buy-this-jacket-black-friday-and-the-new-york-times/story-18615.html.

[6]See Hwang et al. [2016] and Yoon et al. [2020].

[7]The European Commission [2023].

In principle, there are two different ways to design an anti-consumerism campaign. One is to try to stigmatize consumers, which creates a *psychic cost*. For example, a governmental agency may attempt to raise awareness of the negative aspects of meat consumption, which can create a sense of guilt and even disgust.[8] Such a 'stick' effectively reduces the gain from consumption. Alternatively, one could focus on rewarding non-buyers, which creates a *psychic benefit* or 'warm-glow' utility.[9] For example, those who abstain from consumption may take some pride in personally contributing to society's sustainability challenges. Such a 'carrot' effectively raises the gain from nonconsumption.

Taking an economic perspective, anti-consumerism affects the willingness to pay or purchase a product or service. Specifically, by discouraging consumption, it potentially reduces demand, which in turn is likely to have an effect on strategic firm behavior and the welfare of consumers and society as a whole. A key issue is then how to best achieve the objective of lowering consumption levels? Should one advocate a stick approach or a carrot approach instead? It is this issue that we take up in this paper.

We address these and related questions within the context of Hotelling's spatial differentiation model, where two firms compete in prices and are confronted with an anti-consumerism campaign. As is well-known, this setting allows for different types of market situations, ranging from intense competition to (local) monopoly. We provide a complete equilibrium characterization and systematically evaluate the effect of a 'stick' and a 'carrot' on the equilibrium outcomes.

Our main findings are as follows. Both the stick and the carrot approach have a comparable effect on market competition. Specifically, anti-consumerism (weakly) reduces competitive pressure independent of the policy's design ('stick' or 'carrot'). If the market is competitive and the campaign sufficiently effective, then those who are least eager to obtain the product prefer the outside option of 'not consuming'. Anti-consumerism thus potentially transforms competitive markets into (local) monopolies by lowering demand. This demand reduction yields both lower production levels and lower prices, which in turn puts a downward pressure on firms' profitability.

As to consumer and social welfare, a stick negatively affects the utility of consumers who still buy the product. At the same time, it provides no direct benefit for those who forgo consumption. The (weak) reduction in demand has a negative effect on both prices and profits so that firms are worse off too. Taken together, a stick policy is then generally harmful for societal welfare, albeit with one notable exception. If production creates substantial externalities (*e.g.*, emissions) and lowering production yields sufficiently large externality savings, then a stick policy may induce an increase of social welfare. In that case, the cost savings more than make up for the loss in consumer and producer surplus.

By contrast, the impact of a carrot policy on welfare can be positive, even net of externalities. With this approach, consumer surplus can increase when the reduction in aggregate demand is not too big. The reason is that a carrot, although it does not affect the gross utility of consumption, may lead to lower prices. Somewhat paradoxically, therefore, consumers in this case are better off than before the launch of an anti-consumerism campaign. A carrot policy may also have a positive effect on social welfare, even when it leads to a substantial reduction in aggregate demand. Although consumers and producers face a negative direct effect (*i.e.*, both consumer and producer surplus are lower after the launch of the campaign), this may be more than compensated for by the psychic

[8] See, for example, the experimental study by Palomo-Vélez et al. [2018].

[9] See, *e.g.*, Andreoni [1990].

benefits for non-buyers and the externality savings.

Comparing a stick policy with a carrot policy, we show that the carrot performs strictly better than the stick, both in terms of consumer surplus and the welfare of society as a whole. Given that one aims to promote anti-consumerism, therefore, the carrot approach is preferable to the stick approach.

The vastly growing literature dealing with issues of anti-consumption mainly takes a marketing, sociological or psychological perspective.[10] In particular, there is a variety of movements highlighting the problematic features of excessive consumption. The *zero waste* and the *minimalists* are among the most prominent anti-consumption movements.[11] Minimalism focuses on owning less. Pangarkar et al. [2021] identify four types of *minimalism*: (i) *voluntary simplicity*, which opposes conspicuous consumption advocating frugality and self-control in consumption practices; (ii) *reduced consumption*, which simply implies a reduction in consumption, without boycotting or giving up on consumption completely; (iii) *anti-consumption*, which works as a strong dislike and dismissal of consumption practices, mostly for idealistic reasons;[12] and (iv) *inconspicuous minimalism* where individuals decide to exclusively buy products with designs, materials, logos and styles which are discrete in appearance.[13]

A phenomenon closely connected to anti-consumerism is *brand avoidance*. Lee et al. [2009b] distinguish three types of *brand avoidance*: (i) *experiential brand avoidance*, due to a gap between consumers' expectations and experienced brand performance; (ii) *identity brand avoidance*, due to the incongruence between a brand's symbolic meaning and the individual's self-identity, and (iii) *moral brand avoidance*, motivated by ideological incompatibility of the brand with consumers' main political and socio-economic beliefs. It is further worth noting that governments and nongovernmental organizations are also attempting to affect consumers with specific policies such as green nudges, education as well as product design, waste management, and promotion or demotion of particular goods.[14]

Several recent economic studies consider models with vertically differentiated goods in which firms offer both a 'brown' and a 'green' variant (see, *e.g.*, Moraga-Gonzalez and Padron-Fumero [2002]; Rodríguez-Ibeas [2003]; Harstad [2012]; Deltas et al. [2013]). Within these types of setting, consumers typically (partially) internalize the environmental damages generated by the consumption of polluting goods.[15] Espinola-Arredondo and Zhao [2012], for example, study a spatial duopoly where products differ in their degree of pollution. Within this context, it is shown how standard environmental regulations (*e.g.*, taxes and subsidies) may be welfare-enhancing. Recent work by Mantovani and Vergari [2017], Marini et al. [2022], and Maccarrone et al. [2023] employs vertical differentiation models to study how environmentalist and anti-hedonistic campaigns may affect consumers' decisions to buy brown or green products. Among other things, these contributions highlight some potential adverse effects of such policies. In particular, the latter study shows that

[10]See, *e.g.*, Makri et al. [2020] for an extensive survey.

[11]See, *e.g.*, Lee and Ahn [2016] and Meissner [2019].

[12]See, *e.g.*, Zavestoski [2002] and Seegebarth et al. [2016]. Iyer and Muncy [2009] break down anti-consumption behavior further into four sub-categories, including consumers (i) who care for the environment, (ii) who prefer a simple and uncomplicated life without material pursuits, (iii) who avoid specific brands unrespectful to the environment, and (iv) who boycott only certain brands not matching their specific principles and ways of life.

[13]See, *e.g.*, Berger and Ward [2010], Li et al. [2012], Eckhardt et al. [2015], and Seo and Buchanan-Oliver [2019].

[14]See, *e.g.*, Stehfest et al. [2009], Creutzig et al. [2016], Moberg et al. [2019] and Abbott and Sumaila [2019].

[15]See, *e.g.*, Bansal and Gangopadhyay [2003], Amacher et al. [2004], and Lombardini-Riipinen [2005].

when the market is fully covered and consumers are prominently environmentalist, firms maximize differentiation along the environmental quality, negatively affecting the environment.

Our study is further related to the Law and Economics field and, in particular, to work on optimal enforcement. Generally speaking, governments may employ punitive policies (*sanctions*) to deter noncompliance with social and legal norms or, instead, a reward system which provides positive incentives toward the desired behavior. Whether a stick or carrot approach is preferred typically depends on personal traits and contexts, with a balanced strategy often being the most reasonable and effective choice, considering factors like fairness and proportionality while upholding individual rights and societal values.[16] When it comes to anti-consumerism, however, our findings suggest the carrot to be strictly preferable to the stick.

The next section introduces the model. In Section 3, we assess the impact of a stick or carrot policy on market competition. Section 4 deals with consumer surplus, whereas Section 5 focuses on social welfare. Section 6 concludes. All computations and proofs are relegated to the appendix.

## 2.2 The Model

To analyze the impact of anti-consumerism on market competition and welfare, we employ Hotelling's classic spatial differentiation model.[17] There are two price-setting suppliers, firm 1 and firm 2, which are located at the extremes of a unit interval. Without loss of generality, we assume that firm 1 is located at 0 and firm 2 is located at 1. Suppliers produce to order at a common marginal cost $c$ and choose prices simultaneously to maximize profit.

Firm $i$'s profit function is:

$$\Pi_i(p_i, p_j) = (p_i - c) \cdot D_i(p_i, p_j),\ \ i = 1, 2 \text{ and } i \neq j, \tag{2.1}$$

where $D_i$ is its demand, which is a function of the own price, $p_i$, and the price of the rival, $p_j$. Demand comes from a continuum of consumers with unit demand who are uniformly distributed over the interval with a mass normalized to one. The gross surplus from consumption is denoted by $v$, which is assumed to exceed the unit cost of production, *i.e.*, $v > c$.

In addition to paying a price, a buyer based at $x \in [0, 1]$ incurs a transportation cost of $t > 0$ per unit of distance. The parameter $t$ captures the degree of (spatial) product differentiation and can be interpreted as a disutility. The utility function of a consumer located at $x \in [0, 1]$ is then given by:

$$U(x) = \begin{cases} v - p_1 - t \cdot x \text{ when she buys firm 1's product at a price of } p_1, \\ v - p_2 - t \cdot (1 - x) \text{ when she buys firm 2's product at a price of } p_2, \\ 0 \text{ otherwise.} \end{cases} \tag{2.2}$$

We now proceed with analyzing the situation absent an anti-consumerism campaign, which serves as a benchmark for the ensuing stick and carrot analyses.

[16]See, e.g., Balch [1980], De Geest and Dari-Mattiacci [2013], and Galle [2013].
[17]See Hotelling [1929].

### 2.2.1 Price, Output, and Profit: A Benchmark

As is well-known, the parameter values in combination with the price choices may give rise to different types of market situations. Specifically, following Bacchiega et al. [2023] and Yousefimanesh et al. [2023], one can distinguish three different cases:[18]

[$\alpha$] Competitive pricing: $p_1 + p_2 < 2v - t$;

[$\kappa$] Market-sharing pricing: $p_1 + p_2 = 2v - t$;

[$\mu$] Monopolistic pricing: $p_1 + p_2 > 2v - t$.

To facilitate our analysis, it is useful to break down the second case further by delineating two types of market-sharing pricing. If $v \in [c + t, c + \frac{6}{5}t)$, then we speak of *monopolistic market-sharing* and indicate this with $\kappa_1$. If $v \in (c + \frac{6}{5}t, c + \frac{3}{2}t]$, then we use the term *competitive market-sharing* and denote this by $\kappa_2$.

Figure 1 gives a graphical illustration of the different possibilities.

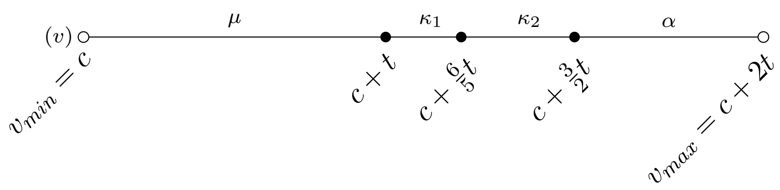


**Figure 2.1:** *Pricing regions in the benchmark.*

Starting from the left, there is the absolute lower bound where gross surplus $v$ equals marginal cost of production $c$. Up until $v = c+t$, the market is 'uncovered' so that firms operate as (local) monopolists. There is market-sharing pricing between $v = c + t$ and $v = c + \frac{3}{2}t$. If $v \in [c + t, c + \frac{6}{5}t)$, then there is monopolistic market-sharing, whereas there is competitive market-sharing when $v \in (c + \frac{6}{5}t, c + \frac{3}{2}t]$. Last, if the valuation for the product is large enough (*i.e.*, $v > c + \frac{3}{2}t$), then there is competitive pricing. This holds until the upper bound, $v = c + 2t$, which derives from the assumption that none of the firms captures the entire market.

We now have all ingredients available to specify the benchmark prices, outputs, and profits. Table 1 provides a complete overview of the equilibrium values.

[18] The symbol that we use to indicate a case is the first letter of the Greek translation. Furthermore, it is worth noting that, strictly speaking, there is a forth 'predatory pricing situation' where one of the firms prices so low that it captures the entire market. We exclude this possibility from our analysis. For a detailed discussion, see Yousefimanesh et al. [2023].

| **Benchmark** | *Monopoly* | *Monopolistic Market-Sharing* | *Competitive Market-Sharing* | *Competition* |
|---|---|---|---|---|
| $p_1^*$ | $\frac{v+c}{2}$ | $\left[\frac{v+c}{2}, \frac{3v-2t-c}{2}\right]$ | $\left[\frac{2v+c}{3}, \frac{4v-3t-c}{3}\right]$ | $c+t$ |
| $p_2^*$ | $\frac{v+c}{2}$ | $\left[\frac{v+c}{2}, \frac{3v-2t-c}{2}\right]$ | $\left[\frac{2v+c}{3}, \frac{4v-3t-c}{3}\right]$ | $c+t$ |
| $D_1^*$ | $\frac{v-c}{2t}$ | $\left[\frac{2t-(v-c)}{2t}, \frac{v-c}{2t}\right]$ | $\left[\frac{v-c}{3t}, \frac{3t-(v-c)}{3t}\right]$ | $\frac{1}{2}$ |
| $D_2^*$ | $\frac{v-c}{2t}$ | $\left[\frac{2t-(v-c)}{2t}, \frac{v-c}{2t}\right]$ | $\left[\frac{v-c}{3t}, \frac{3t-(v-c)}{3t}\right]$ | $\frac{1}{2}$ |
| $\Pi_1^*$ | $\frac{(v-c)^2}{4t}$ | $\left[\frac{(v-c-2t)\cdot(2t-3(v-c))}{4t}, \frac{(v-c)^2}{4t}\right]$ | $\left[\frac{2(v-c)^2}{9t}, \frac{(v-c-3t)\cdot(3t-4(v-c))}{9t}\right]$ | $\frac{1}{2}t$ |
| $\Pi_2^*$ | $\frac{(v-c)^2}{4t}$ | $\left[\frac{(v-c-2t)\cdot(2t-3(v-c))}{4t}, \frac{(v-c)^2}{4t}\right]$ | $\left[\frac{2(v-c)^2}{9t}, \frac{(v-c-3t)\cdot(3t-4(v-c))}{9t}\right]$ | $\frac{1}{2}t$ |

**Table 2.1:** *Equilibrium prices, outputs, and profits in the benchmark.*

Table 1 reveals an equilibrium pricing pattern as visualized in Figure 2.

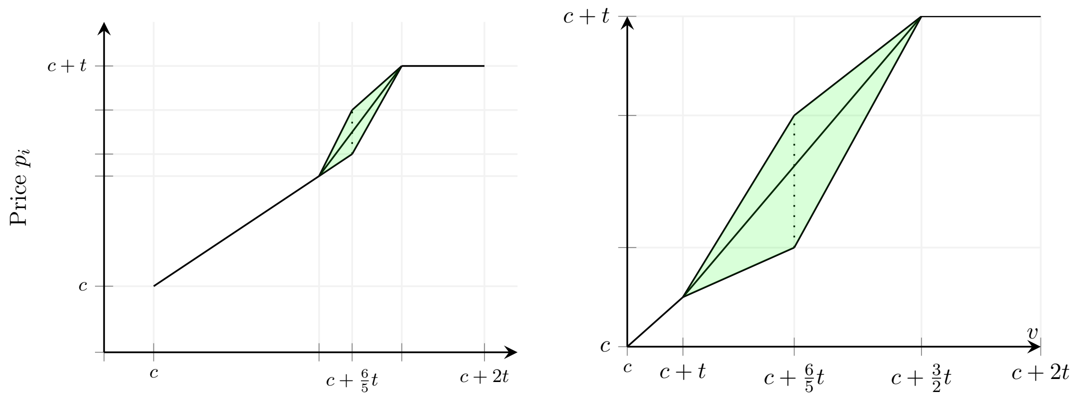


**Figure 2.2:** *Equilibrium pricing pattern.*

Prices are lowest under (local) monopoly. In that case, the valuation for the product is so low that consumers which are least eager to obtain it (*i.e.*, the ones located in the middle) choose the outside option. These customers do prefer to purchase when $v$ exceeds the threshold $c+t$. Under market-sharing pricing ($i.e.$, $v \in \left[c+t, c+\frac{3}{2}t\right]$), prices are increasing over the entire range and higher than under monopoly. Specifically, in this case there is a range of equilibrium prices. The difference between the lowest and highest equilibrium price increases over the range $\left[c+t, c+\frac{6}{5}t\right)$, whereas this difference decreases over the range $\left(c+\frac{6}{5}t, c+\frac{3}{2}t\right]$. Maximal equilibrium price dispersion may therefore occur at $v = c+\frac{6}{5}t$. When $v$ exceeds the threshold $c+\frac{3}{2}t$, the market is in the competitive region. Under competitive pricing, prices are independent of the valuation and given by $c+t$. This is the highest possible benchmark equilibrium price.

As to demand, under competitive pricing this is constant and given by $\frac{1}{2}$ for each firm. With market-sharing, it depends on the degree of price dispersion. Firms share the market equally at equal prices. If prices differ, then it is the higher-priced firm that has the lower market share. Under monopoly, there is a positive relation between price and demand. That is, an increase in the valuation for the product leads to higher demand, which results in higher equilibrium prices.

Finally, it can be easily verified that equilibrium profits are monotonically increasing in $v$. That is, profits under market-sharing pricing exceed profits under monopoly pricing. Moreover, profits under competitive pricing are higher than with market sharing for all equilibrium specifications.

### 2.2.2 Consumer Surplus and Social Welfare: A Benchmark

Let us now consider the welfare of consumers and of society at large. Consumer surplus ($CS$) is given by buyers' joint utility and computed as follows:

$$CS = \int_0^{x_1} U(x)dx + \int_{x_2}^{1} U(x)dx. \tag{2.3}$$

The boundary values $x_1$ and $x_2$ depend on which market situation applies. Under competitive pricing, the equilibrium is such that $x_1 = x_2 = \frac{1}{2}$, *i.e.*, each firm serves half the market. With market-sharing $x_1 + x_2 = 1$, but market shares may differ. Finally, under local monopoly it holds that $x_1 = x_2$ and $x_1 + x_2 < 1$.

Social welfare ($W$) is given by:

$$W = CS + N + \Pi_1 + \Pi_2 - E, \tag{2.4}$$

where $N$ represents non-buyers' surplus. Note that, by the above utility specification (2), $N$ equals zero in the benchmark. Externalities from production (*e.g.*, emissions) are captured by the function $E : D \mapsto \mathbb{R}_+$, where $D = D_1 + D_2$ is total output. It is assumed that $E$ is a continuously increasing function on $[0, 1]$ with $E(0) = 0$ and $E(1) < \infty$. In what follows, let $e$ and $e_u$ denote the equilibrium externality when the market is 'covered' (*i.e.*, when $D = 1$) and 'uncovered' (*i.e.*, when $D < 1$), respectively. Note that this implies $e > e_u$.

Table 2 provides an overview of consumer surplus and social welfare in the benchmark equilibrium.

| **Benchmark** | $CS^*$ | $W^*$ |
|---|---|---|
| *Monopoly* | $\frac{(v-c)^2}{4t}$ | $\frac{3(v-c)^2}{4t} - e_u$ |
| *Mon. MS* | $\left[\frac{1}{4}t, \frac{(v-c)\cdot(v-c-2t)}{4t} + \frac{1}{2}t\right]$ | $\left[\frac{(v-c)\cdot(6t-(v-c))}{4t} - \frac{1}{2}t - e, v - c - \frac{1}{4}t - e\right]$ |
| *Comp. MS* | $\left[\frac{1}{4}t, \frac{(v-c)\cdot(v-c-3t)}{9t} + \frac{1}{2}t\right]$ | $\left[\frac{(v-c)\cdot(12t+c-v)}{9t} - \frac{1}{2}t - e, v - c - \frac{1}{4}t - e\right]$ |
| *Competition* | $v - c - \frac{5}{4}t$ | $v - c - \frac{1}{4}t - e$ |

**Table 2.2:** *Consumer surplus and social welfare in the benchmark.*

Consumer surplus is in the range $[0, \frac{3}{4}t]$, where the lower bound is at $v_{min} = c$ and the upper bound is at $v_{max} = c + 2t$. It is larger under competition than under monopoly. Interestingly, under market-sharing its value critically depends on the price difference. In this region, the minimum value is $\frac{1}{4}t$, which is obtained at equal prices (*i.e.*, $p_1^* = p_2^* = v - \frac{1}{2}$). Note that this is the same value as on the boundary between monopoly and market-sharing (*i.e.*, when $v = c + t$) and market-sharing and competition (*i.e.*, when $v = c + \frac{3}{2}t$). Under market-sharing, consumer surplus positively depends on the price difference. This is because buyers benefit from lower prices and the lower-priced firm has the larger market share. Given that the market is covered, price dispersion thus works to the advantage of consumers. The maximum value of $\frac{13}{50}t$ ($> \frac{1}{4}t$) is obtained on the boundary between monopolistic and competitive market-sharing (*i.e.*, when $v = c + \frac{6}{5}t$).

Net of externalities, social welfare is monotonically increasing in $v$. This has the implication that social welfare is higher under competitive pricing than under market-sharing pricing since the level of externalities is the same in both situations. Unlike with consumer welfare, there is no non-monotonic pattern in this case, because in the market-sharing region the consumers' gain from lower prices is more than offset by the firms' loss in profits. Whether social welfare in the competitive region exceeds social welfare under monopoly critically depends on the degree of externalities. It is larger (smaller) under competitive pricing than under monopoly pricing when the difference $e - e_u$ is sufficiently small (large).

## 2.3 Competition in the Presence of a Stick or Carrot

Having in mind the above benchmark, let us now analyze the impact of an anti-consumerism campaign that either creates a psychic cost (a 'stick') or a psychic reward (a 'carrot') on market competition. The direct impact of the campaign is captured with a parameter $a > 0$. It is assumed that the impact is not too big in that it does not bring the effective gross surplus $v - a$ below marginal cost, *i.e.*, $a \in (0, v - c)$.

A 'stick policy' effectively reduces the benefit of consumption. Those who still buy are worse off. The consumer's utility specification (2) is then adapted in the following way, where the superscript 's' indicates the presence of a stick:

$$U^s(x) = \begin{cases} v - a - p_1 - tx \text{ when she buys firm 1's product at a price of } p_1, \\ v - a - p_2 - t(1-x) \text{ when she buys firm 2's product at a price of } p_2, \\ 0 \text{ otherwise.} \end{cases} \tag{2.5}$$

By contrast, a 'carrot policy' creates a benefit for those who forgo consuming the good or service. In this case, the consumer's utility specification (2) is modified as follows:

$$U^c(x) = \begin{cases} v - p_1 - tx \text{ when she buys firm 1's product at a price of } p_1, \\ v - p_2 - t(1-x) \text{ when she buys firm 2's product at a price of } p_2, \\ a \text{ otherwise.} \end{cases} \tag{2.6}$$

The superscript 'c' indicates the presence of a carrot.

Like in the benchmark, we can distinguish three different pricing regions. Both with a stick and a carrot approach, these are given by:

$[\alpha^s]/[\alpha^c]$ Competitive pricing $p_1 + p_2 < 2(v - a) - t$;

$[\kappa^s]/[\kappa^c]$ Market-sharing pricing $p_1 + p_2 = 2(v - a) - t$;

$[\mu^s]/[\mu^c]$ Monopolistic pricing $p_1 + p_2 > 2(v - a) - t$.

Since the stick and carrot policy have the same impact on the benchmark pricing regions, one *a priori* may expect their effect on prices, outputs, and profits to be the same too. Given that the anti-consumerism campaign is equally effective in both situations, this indeed appears to be the case.

Table 3 is directly comparable to Table 1 and provides an overview of the equilibrium values under either a stick or a carrot policy.

| **Stick/Carrot** | *Monopoly* | *Monopolistic Market-Sharing* | *Competitive Market-Sharing* | *Competition* |
|---|---|---|---|---|
| $p_1^*$ | $\frac{v-a+c}{2}$ | $\left[\frac{v-a+c}{2}, \frac{3(v-a)-2t-c}{2}\right]$ | $\left[\frac{2(v-a)+c}{3}, \frac{4(v-a)-3t-c}{3}\right]$ | $c+t$ |
| $p_2^*$ | $\frac{v-a+c}{2}$ | $\left[\frac{v-a+c}{2}, \frac{3(v-a)-2t-c}{2}\right]$ | $\left[\frac{2(v-a)+c}{3}, \frac{4(v-a)-3t-c}{3}\right]$ | $c+t$ |
| $D_1^*$ | $\frac{v-a-c}{2t}$ | $\left[\frac{2t-(v-a-c)}{2t}, \frac{v-a-c}{2t}\right]$ | $\left[\frac{v-a-c}{3t}, \frac{3t-(v-a-c)}{3t}\right]$ | $\frac{1}{2}$ |
| $D_2^*$ | $\frac{v-a-c}{2t}$ | $\left[\frac{2t-(v-a-c)}{2t}, \frac{v-a-c}{2t}\right]$ | $\left[\frac{v-a-c}{3t}, \frac{3t-(v-a-c)}{3t}\right]$ | $\frac{1}{2}$ |
| $\Pi_1^*$ | $\frac{(v-a-c)^2}{4t}$ | $\left[\frac{(v-a-c-2t)\cdot(2t-3(v-a-c))}{4t}, \frac{(v-a-c)^2}{4t}\right]$ | $\left[\frac{2(v-a-c)^2}{9t}, \frac{(v-a-c-3t)\cdot(3t-4(v-a-c))}{9t}\right]$ | $\frac{1}{2}t$ |
| $\Pi_2^*$ | $\frac{(v-a-c)^2}{4t}$ | $\left[\frac{(v-a-c-2t)\cdot(2t-3(v-a-c))}{4t}, \frac{(v-a-c)^2}{4t}\right]$ | $\left[\frac{2(v-a-c)^2}{9t}, \frac{(v-a-c-3t)\cdot(3t-4(v-a-c))}{9t}\right]$ | $\frac{1}{2}t$ |

**Table 2.3:** *Equilibrium prices, outputs, and profits under a stick or carrot policy.*

To assess the impact of anti-consumerism, let us start by assuming that the market is competitive prior to the launch of the campaign. We then have the following result.

**Proposition 8** *Assume competitive pricing ex ante, i.e.* $v \in (c + 1.5t, c + 2t)$, *and suppose that a stick or carrot policy is introduced:*
*(i) If* $a$ *is sufficiently small such that there is competitive pricing ex post, then prices, outputs, and profits are not affected.*
*(ii) If* $a$ *is sufficiently large such that there is market-sharing pricing ex post, then prices and profits are lower than in the benchmark. Aggregate production is not affected.*
*(iii) If* $a$ *is sufficiently large such that there is monopolistic pricing ex post, then prices, outputs, and profits are lower than in the benchmark.*

This result reveals that the anti-consumerism campaign must be impactful enough to have an effect on strategic firm behavior when the market is competitive. Simply put, consumers will not change their behavior unless the psychic effect created is sufficiently severe. A large enough stick or carrot will induce those least eager to obtain the product to leave the market. The resulting drop in demand leads to a reduction of both price and profit.

The next two results show the effect under market-sharing and monopolistic pricing, respectively.

**Corollary 9** *Assume market-sharing pricing ex ante, i.e.* $v \in [c + t, c + \frac{3}{2}t]$, *and suppose that a stick or carrot policy is introduced:*
*(i) If* $a$ *is sufficiently small such that there is market-sharing pricing ex post, then prices and profits are lower than in the benchmark. Aggregate production is not affected.*
*(ii) If* $a$ *is sufficiently large such that there is monopolistic pricing ex post, then prices, outputs, and profits are lower than in the benchmark.*

**Corollary 10** *Assume monopolistic pricing, i.e.* $v \in (c, c+t)$. *If a stick or carrot policy is introduced, then prices, outputs, and profits are lower than in the benchmark.*

In sum, whether an anti-consumerism campaign creates a psychic cost or a psychic reward, the impact on market competition is the same. Unless the market remains competitive after the launch of the campaign, both a stick and a carrot policy put downward pressure on prices and profits. This leads to a lower aggregate output only if either (i) it 'uncovers' the market, *i.e.*, it induces some consumers to no longer buy the product, or (ii) the market is already 'uncovered' prior to the campaign.

## 2.4 Consumer Surplus

Let us now turn to the question of how an anti-consumerism campaign affects consumer surplus as specified in (3) above. Table 4 provides an overview of the surplus equilibrium values under both types of policy.

| **Consumer Surplus** | *Stick* | *Carrot* |
|---|---|---|
| *Monopoly* | $\frac{(v-a-c)^2}{4t}$ | $\frac{(v-a-c)\cdot(v+3a-c)}{4t}$ |
| *Mon. MS* | $\left[\frac{1}{4}t, \frac{(v-a-c)\cdot(v-a-c-2t)}{4t} + \frac{1}{2}t\right]$ | $\left[\frac{1}{4}t + a, \frac{(v-a-c)\cdot(v-a-c-2t)}{4t} + \frac{1}{2}t + a\right]$ |
| *Comp. MS* | $\left[\frac{1}{4}t, \frac{(v-a-c)\cdot(v-a-c-3t)}{9t} + \frac{1}{2}t\right]$ | $\left[\frac{1}{4}t + a, \frac{(v-a-c)\cdot(v-a-c-3t)}{9t} + \frac{1}{2}t + a\right]$ |
| *Competition* | $v - a - c - \frac{5}{4}t$ | $v - c - \frac{5}{4}t$ |

**Table 2.4:** *Consumer surplus under a stick or carrot policy.*

### Stick

Since a stick policy reduces the benefit of consumption, one *a priori* may expect this approach to lead to a lower consumer surplus. The following two findings confirm this, albeit with one notable exception.

**Proposition 11** *Suppose that a stick policy is introduced that does not induce a switch in pricing regions.*
*(i) Consumer surplus under competitive and monopolistic pricing is lower than in the benchmark. Consumer surplus under monopolistic market-sharing pricing is weakly lower than in the benchmark.*
*(ii) Consumer surplus under competitive market-sharing pricing is weakly higher than in the benchmark.*

Clearly, when the market is competitive *ex ante* and remains competitive *ex post*, the stick is detrimental to consumer welfare. This is because all buyers still prefer to purchase at the same price (see Table 3) even though their valuation for the product has been reduced. The stick policy brings down consumer surplus also when the market is monopolistic. As with competition, those who still buy are worse off. Additionally, those who did not receive much utility from consumption *ex ante* may prefer the outside option *ex post*. Indeed, a stick policy in this case induces some customers to leave the market, which too lowers consumer surplus.

The stick has a more subtle impact on consumer surplus under market-sharing pricing. Indeed, if there is competitive market-sharing *ex ante* and the stick policy is such that there is competitive market-sharing *ex post*, then the welfare of consumers *increases*. In this case, there are three distinct factors that simultaneously affect consumer surplus. First, each consumer still prefers to buy the product, but now experiences a psychic cost when doing so. This decreases the benefit of consumption. Second, the range of equilibrium prices narrows (see Table 3) and the price difference decreases.[19] This, too, has a negative effect on consumer welfare. Third and lastly, the reduction in gross surplus creates a downward pressure on (equilibrium) prices, which works to the advantage of consumers. In the competitive market-sharing region, the positive 'price effect' dominates the negative 'surplus and dispersion effect' so that consumer welfare is higher than in the benchmark. By contrast, in the monopolistic market-sharing region, the 'surplus and dispersion effect' dominates the 'price effect'. In this case, therefore, a stick campaign reduces consumer welfare.

Finally, recall that what type of pricing applies critically depends on the level of gross surplus $v$ (see Figure 1). Since a stick policy directly affects gross surplus (it changes from $v$ to $v - a$), it potentially brings about a switch to another pricing region. For example, a competitive market may turn into a monopolistic one when the campaign is sufficiently effective. In light of the preceding analysis, this always leads to a reduction of consumer welfare with one notable exception. If $v$ is above, but sufficiently close to, $c + \frac{3}{2}t$ *ex ante* and $v - a$ is sufficiently close to $c + \frac{6}{5}t$ *ex post*, then the 'price effect' dominates the 'surplus effect', which implies an increase in consumer surplus. The next corollary loosely summarizes this finding.

**Corollary 12** *Suppose that a stick policy is introduced that does induce a switch in pricing regions. Consumer surplus may increase only when the stick policy brings the market from the competitive into the market-sharing region.*

### Carrot

Let us now evaluate the carrot's effect on consumer surplus. The following proposition is directly comparable to Proposition 11 and shows the impact of a carrot policy on consumer welfare when it does not result in a switch in pricing regions.

**Proposition 13** *Suppose that a carrot policy is introduced that does not induce a switch in pricing regions.*
*(i) Consumer surplus under competitive pricing is the same as in the benchmark.*
*(ii) Consumer surplus under market-sharing is higher than in the benchmark.*
*(iii) If $a$ is sufficiently large (small), then consumer surplus under monopolistic pricing is lower (higher) than in the benchmark.*

Consumer surplus is the same as in the benchmark under competitive pricing. This is because, after the launch of the campaign, all buyers still purchase the product at the same price (see Table 1 and Table 3) and enjoy the same gross surplus. Unlike with the stick policy, there is no psychic cost in this case. For a given equilibrium price configuration, consumer welfare is higher than in the benchmark under market-sharing pricing. The reason is that, in this case, the carrot policy incentivizes firms to charge lower prices (see Table 1 and Table 3). Given that gross surplus remains unaffected and all consumers buy *ex ante* as well as *ex post*, this implies an increase in consumer surplus. Finally, under monopolistic pricing, whether consumer surplus is lower or higher than in the benchmark critically depends on the effectiveness of the anti-consumerism campaign. In this case, there are two opposing effects. On the one hand, the carrot leads to lower prices. On the other hand, it induces consumers to leave the market. This negative demand effect dominates the positive

[19] Note that this effect is absent when the benchmark prices are identical.

price effect when $a$ is sufficiently high and *vice versa*. Note that in this case there is a benefit of nonconsumption. Specifically, non-buyer surplus is given by:

$$N = a \cdot (1 - D)\,. \tag{2.7}$$

Figure 2.3 provides a graphical illustration. Consider the graphical example below:

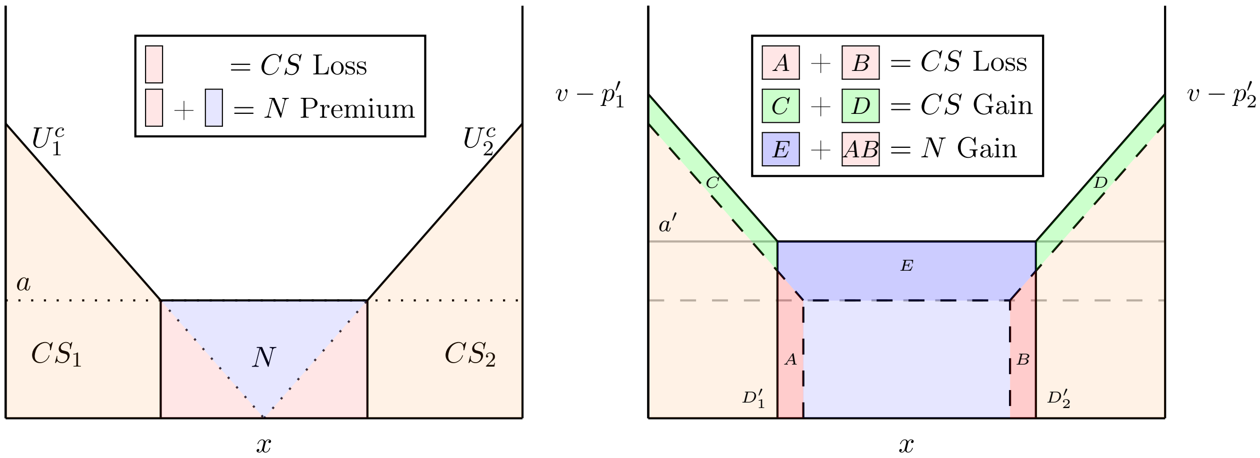


**Figure 2.3:** *Anti-consumerism effect under the carrot monopolistic region.*

An increase in anti-consumerism always reduces prices (green areas (C) and (D)) and production levels (red areas (A) and (B)), yielding opposite effects on consumer surplus. A reduction occurs only because the consumers with taste distribution values far from the ideal types, that is, from average values of $x$, now prefer to refrain from buying as they are more satisfied with the outside option. However, the discount on prices increases consumers' utility, and this latter effect dominates in this example. The non-buyers surplus, the blue area (E), always increases as they enjoy increasing levels of the carrot policy.

### Comparison

Finally, let us conclude this section by comparing the stick and carrot policy. The next result shows that consumer surplus is unambiguously higher with a carrot approach.

**Theorem 14** *For any given level of anti-consumerism, consumer surplus is larger under a carrot policy than under a stick policy.*

The intuition underlying this finding is as follows. Both policies have the same effect on prices (Table 3), but a different effect on gross surplus. The stick policy reduces gross surplus, whereas it is unaffected with a carrot approach. Combining the 'price effect' and the 'surplus effect' yields the conclusion in Theorem 14.

## 2.5 Social Welfare

How does anti-consumerism affect the welfare of society as a whole? In this section, we address this question and compare the impact of a stick and a carrot policy on total welfare as given by (4) above. Table 5 provides an overview of the equilibrium values.

| **Social Welfare** | *Stick* | *Carrot* |
|---|---|---|
| *Monopoly* | $\frac{3(v-a-c)^2}{4t} - e_u^s$ | $\frac{3(v-a-c)^2}{4t} - e_u^c + a$ |
| *Mon. MS* | $\left[\frac{(v-a-c)\cdot(6t-(v-a-c))}{4t} - \frac{1}{2}t - e, v - c - \frac{1}{4}t - e - a\right]$ | $\left[\frac{(v-a-c)\cdot(6t-(v-a-c))}{4t} - \frac{1}{2}t - e + a, v - c - \frac{1}{4}t - e\right]$ |
| *Comp. MS* | $\left[\frac{(v-a-c)\cdot(12t-(v-a-c))}{9t} - \frac{1}{2}t - e, v - c - \frac{1}{4}t - e - a\right]$ | $\left[\frac{(v-a-c)\cdot(12t-(v-a-c))}{9t} - \frac{1}{2}t - e + a, v - c - \frac{1}{4}t - e\right]$ |
| *Competition* | $v - c - \frac{1}{4}t - e - a$ | $v - c - \frac{1}{4}t - e$ |

**Table 2.5:** *Social welfare under a stick or carrot policy.*

## Stick

Starting with the stick, the next result shows the impact of this approach on social welfare.

**Proposition 15** *Suppose that a stick policy is introduced that does not induce a switch in pricing regions.*
*(i) Social welfare under competitive and market-sharing pricing is lower than in the benchmark.*
*(ii) If the externality reduction is sufficiently small (large), then social welfare under monopolistic pricing is lower (higher) than in the benchmark.*

In the competitive pricing region, the stick has no effect on profits (Proposition 8), but it lowers consumer surplus (Proposition 11). As the market remains ‘covered’, there is neither non-buyer surplus, nor a reduction of the negative externality. Taken together, this implies that social welfare goes down in this case. The story is pretty much the same with monopolistic market-sharing, but for the profit effect. In this situation, a stick policy leads to a reduction of profits (Corollary 9), which reinforces the negative impact on social welfare. With competitive market-sharing, the effect on consumer surplus is positive (Proposition 11). This, however, is more than offset by the decrease in profits (Proposition 8). Finally, under monopolistic pricing, the impact critically depends on the externality. Net of externalities, the stick policy reduces social welfare since both profits and consumer surplus are lower than in the benchmark and there is no benefit for non-buyers. Yet, this negative effect can potentially be offset by the decrease in externalities. That is, if the reduction in externality resulting from the decrease in outputs is sufficiently large, then the overall effect on social welfare is positive.

By the preceding logic, a stick policy that induces a switch in pricing regions can only be beneficial for social welfare when (i) it reduces aggregate production, and (ii) this reduction yields sufficient externality cost savings. The next corollary summarizes this finding.

**Corollary 16** *Suppose that a stick policy is introduced that does induce a switch in pricing regions. Social welfare increases only when the stick policy brings the market into the monopolistic pricing region and the reduction in externalities is sufficiently large.*

## Carrot

Let us now turn to the impact of a carrot policy on social welfare. Note that in this case there is a benefit of nonconsumption as shown in Figure 2.3.

The next result is comparable to Proposition 15 and describes the impact of a carrot policy on social welfare.

**Proposition 17** *Suppose that a carrot policy is introduced that does not induce a switch in pricing regions.*
*(i) Social welfare under competitive pricing is the same as in the benchmark.*
*(ii) Social welfare under competitive market-sharing pricing is weakly lower than in the benchmark.*
*(iii) Social welfare under monopolistic market-sharing pricing is weakly higher than in the benchmark.*
*(iv) If $a$ is sufficiently large, then social welfare under monopolistic pricing is higher than in the benchmark.*

There is no effect under competitive pricing, because there is no effect on profits (Proposition 8) or consumer surplus (Proposition 13). Moreover, since the market remains 'covered', there is no change in non-buyer surplus or the level of externalities. The latter two factors do also not change under market-sharing pricing. Yet, consumer surplus increases (Proposition 13) and profits decrease (Proposition 8). In this case, the net effect critically depends on the level of price dispersion.

If prices are identical, then the carrot results in a monetary transfer from producers to consumers and social welfare is the same as in the benchmark. If prices differ, then the carrot reduces equilibrium price dispersion. One can verify that price dispersion is beneficial for consumer welfare and harmful for aggregate profits. Under competitive market-sharing pricing, the reduced price difference has a larger effect on consumers than on producers. As a result, social welfare is lower than in the benchmark. By contrast, under monopolistic market-sharing pricing, the effect on profits outweighs the effect on consumer surplus. In this case, therefore, social welfare is higher than in the benchmark.

Finally, under monopolistic pricing, the carrot is always beneficial for social welfare provided that it is sufficiently big. The reason is that there is a threshold above which the non-buyer surplus and externality cost savings are large enough to outweigh the combined loss in profits (Corollary 10) and consumer surplus (Proposition 13).

### Comparison

As with consumer surplus, let us conclude this section by comparing the stick and carrot policy. A casual glimpse at Table 5 reveals the carrot to dominate the stick in terms of social welfare.

**Theorem 18** *For any given level of anti-consumerism, social welfare is larger under a carrot policy than under a stick policy.*

The policy implication is thus crystal clear. If one aims to promote an anti-consumerism campaign, then the carrot is the preferred mode of action.

## 2.6 Concluding Remarks

Anti-consumerism is a doctrine that is recently gaining *momentum*. With an eye on the current environmental challenges, it aims to discourage excessive consumption. Given that this affects consumers, producers and society as a whole, a key question is how to best pursue this goal. Anti-consumerism could focus on buyers by creating psychic costs for those who consume. Alternatively, it may attempt to create psychic benefits for those who forgo buying a product or service. In this paper, we showed that the effect of both approaches on market competition is comparable. Independent of whether one uses a 'stick' or a 'carrot', anti-consumerism (weakly) reduces competitive pressure and leads to (weakly) lower prices, outputs and profits. The impact on welfare differs, however. Indeed, both consumers and society at large are better off with a carrot approach.

In terms of policy implications, our findings thus show that the 'carrot' should be strictly preferred to the 'stick'. This leaves the question of whether an anti-consumerism 'carrot' campaign should be preferred to no campaign at all. Our analysis suggests this question to be everything but trivial. A richer analysis should consider the costs to examine under which conditions the implementation of each approach is socially desirable. Assuming that anti-consumerism manifests itself as an environmental campaign, the costs depend on common factors such as content production and distribution channels. For this reason, the costs could be similar or even the same. However, the aversion of some distribution channels to punitive messages and other individual behavioral phenomena could create cost asymmetries. Furthermore, choosing a punitive or rewarding tool depends on the target market and the policymaker's intentions. For example, considering cigarettes, a graphic depiction of the warning causes fear in consumers and helps in consumption reduction. Instead, organic food often embeds a promise of joy and happiness. Generally, there is a connection between the social desirability of the good and the chosen approach for the campaign, whether punitive or rewarding. These considerations will be the subject of future research.

Regarding this chapter, although such a campaign (weakly) lowers firm profits and production levels, its effect on consumer and social welfare critically depends on the market situation absent anti-consumerism. For example, if gross surplus is significant, then the carrot must be significant too to have an impact. Indeed, when goods are considered 'essential' and consumers have limited outside options, the carrot may be insufficient to affect consumer decisions. By contrast, a carrot always has an effect when gross surplus is sufficiently small. Taken together, this suggests a positive relationship between the effectiveness of an anti-consumerism 'carrot' campaign and the price elasticity of market demand. This, arguably, is an important issue that warrants a more detailed assessment. We leave this for future research.

## 2.7 Appendix

### 2.7.1 Derivation of Table Values

In this subsection, we explain how one can derive the equilibrium values in Tables 1-5.

#### Competitive and Monopolistic Pricing

Nash equilibrium prices in the *monopolistic* and *competitive* pricing regions can be computed as in the textbook Hotelling model. Firms' demand functions are obtained by identifying the location of consumers who are indifferent between buying good 1 and not buying ($U_1(x) = 0$), which gives $x_1 = (v - p_1)/t$, between buying good 2 and not buying ($U_2(x) = 0$), which gives $x_2 = 1-(v - p_2)/t$, or between buying good 1 and good 2 ($U_1(x) = U_2(x)$), which gives $x_3 = (p_2 - p_1 + t)/2t$. In the presence of an anti-consumerism campaign, under both a stick and a carrot policy, one obtains $x_1 = (v - p_1 - a)/t$, $x_2 = 1 - (v - p_1 - a)/t$, and $x_3 = (p_2 - p_1 + t)/2t$ instead. Excluding corner solutions, demand for the products of firm 1 is then given by $D_1 = \min\{x_1, x_3\}$, whereas for firm 2 it is given by $D_2 = 1 - \max\{x_2, x_3\}$.

Recall that a firm's profit function is:

$$\Pi_i(p_i, p_j) = (p_i - c) \cdot D_i(p_i, p_j), \; i = 1, 2 \text{ and } j \neq i.$$

It is straightforward to check that the profit functions are concave. Specifically, the second-order conditions are satisfied for $t > 0$, which also guarantees that the equilibrium prices exceed costs, *i.e.*, $p_i^* > c$, for $i = 1, 2$, both for the benchmark and for the stick and carrot cases. The first-order conditions, therefore, suffice to determine the equilibrium prices reported in Table 1 and 3.

Turning to welfare, recall that consumer surplus is given by:

$$CS = \int_0^{x_1} U(x)\mathrm{d}x + \int_{x_2}^1 U(x)\mathrm{d}x.$$

Both in the benchmark as well as with anti-consumerism, it suffices to consider the equilibrium prices in the utility functions as well as in the integrals' extrema, which depends on what case applies. To illustrate, consumer surplus under a carrot policy in the monopolistic pricing region is:

$$CS^c = \int_0^{x_1} U^c(x)\mathrm{d}x + \int_{x_2}^1 U^c(x)\mathrm{d}x.$$

It is noteworthy that one can derive the same value geometrically. For instance, in case of a carrot policy in the monopolistic pricing region, it holds that:

$$CS^c = \frac{x_1}{2}\left[U_1^c(0) + a\right] + \frac{x_2}{2}\left[U_2^c(1) + a\right].$$

Both approaches yield:

$$CS^c = \frac{(v - a - c) \cdot (v + 3a - c)}{4t}.$$

Social welfare is obtained by adding equilibrium profits, consumer and non-buyer surplus, and subtracting the negative production externalities.

**Market-Sharing Pricing**

For the market-sharing pricing region, one can use Theorem 3.6 in Yousefimanesh et al. [2023]. There, it is shown there is a line segment of price equilibria given by:

$$(p_1^*, p_2^*) = (2v - t - \lambda, \lambda).$$

That is, there is a combination of prices that respect the market-sharing condition. Specifically, $\lambda$ is such that:

$$\max\{3v + 3c, 8v - 6t - 2c\} \leq 6\lambda \leq \min\{4v + 2c, 9v - 6t - 3c\}.$$

Comparing the upper and lower bound of the above inequality, we find that when $c+t \leq v < c+(6/5)t$, it holds that $(3/2)v - c/2 - t \geq \lambda \geq (v + c)/2$. Plugging these values in the equilibrium prices yields the monopolistic market-sharing pricing range:

$$(p_1^*, p_2^*) \in [\frac{v+c}{2}, \frac{3v - 2t - c}{2}].$$

For any firm's equilibrium price in the interval, the rival's price can be directly obtained from the market-sharing condition, *i.e.*, $p_1 + p_2 = 2v - t$. If $c + (6/5)t < v \leq c + (3/2)t$, then $(2/3)\,v + c/3 \geq \lambda \geq (4/3)\,v - t - c/3$. Plugging these values in the equilibrium prices yields the competitive market-sharing pricing range:

$$(p_1^*, p_2^*) \in [\frac{4v - 3t - c}{3}, \frac{2v + c}{3}].$$

Finally, for $v = c + (6/5)t$, we obtain

$$(p_1^*, p_2^*) \in [c + (3/5)t, c + (4/5)t].$$

Notice that on the boundary of the *competitive* and *monopolistic market-sharing* region (*i.e.* at $v = c + (3/2)t$ and $v = c + t$, respectively), the equilibrium prices are equal to the ones in the *competitive* and *monopolistic* pricing region (*i.e.*, $(p_1^*, p_2^*) = c + t$ and $(p_1^*, p_2^*) = (v + c)/2$), respectively), which establishes the continuity of equilibrium prices in Figure 1.

By plugging the equilibrium prices in the benchmark demand and profit functions, one obtains the range of equilibrium values in the two market-sharing regions $\kappa_1$ and $\kappa_2$ as presented in Table 1. Analogously, starting from the *market-sharing condition* under stick or carrot, *i.e.*, $p_1+p_2 = 2(v-a)-t$, the interval for price equilibrium profiles is given by:

$$\max\{\frac{4}{3}(v-a) - \frac{1}{3}c - t, \frac{1}{2}(v - a + c)\} \leq \lambda \leq \min\{\frac{3}{2}(v-a) - \frac{1}{2}c - t, \frac{2}{3}(v-a) + \frac{1}{3}c\}.$$

Therefore, in the *monopolistic market-sharing* region, for $v - c - (6/5)t < a \leq v - c - t$, we obtain

$$(p_1^*, p_2^*) \in [\frac{v - a + c}{2}, \frac{3\,(v-a) - 2t - c}{2}],$$

whereas in the *competitive market-sharing* region, for $v - c - (3/2)t \leq a < v - c - (6/5)t$, we obtain

$$(p_1^*, p_2^*) \in \left[\frac{2(v-a) + c}{3}, \frac{4(v-a) - 3t - c}{3}\right].$$

Finally, for $a = v - c - (6/5)t$, prices are

$$(p_1^*, p_2^*) \in [c + (3/5)t, c + (4/5)t].$$

By substituting the equilibrium prices in the demand and profit functions in the presence of an anti-consumerism campaign, we obtain the range of equilibrium values as presented in Table 3. Finally, it is worth noting that the sum of profits is concave in the entire *market-sharing* region and maximal when firms set equal prices, *i.e.*, when there is no price dispersion.

Recall that consumer surplus is given by:

$$CS = \int_0^{x_1} U(x)\mathrm{d}x + \int_{x_2}^{1} U(x)\mathrm{d}x. \tag{2.8}$$

As indicated above, its value can be computed by substituting the equilibrium prices into the utility functions and the applicable integrals' extrema. Moreover, the *market-sharing conditions*, *i.e.* $p_1 + p_2 = 2v - t$ in the benchmark and $p_1 + p_2 = 2(v - a) - t$ with anti-consumerism, must hold. Using these constraints, one can show that (2.8) is convex in both prices, reaching its *minimum* when there is no *price dispersion* and firms set equal prices in the *market-sharing* interval. This implies that consumer surplus is highest with maximal *price dispersion*.

A similar rationale applies in case of social welfare, which is concave in the entire market-sharing region. Hence, it is maximal when there is no price dispersion and minimal when prices are on the boundary of the equilibrium price range. These values are reported in Table 5.

### 2.7.2 Proofs

**Proof of Proposition 1.**
(i) Both a stick and a carrot policy basically induce an effective reduction of the consumers' gross surplus $v$ of magnitude $a$. Therefore, if firms are initially in the competitive region (*i.e.*, $v \in (c + 1.5t, c + 2t))$ and the magnitude of the stick or carrot is not big enough to induce a switch in pricing region, equilibrium prices remain unaffected. Consequently, there is no change in output or profit either (see Table 1 and Table 3).
(ii) If the magnitude of the stick or carrot is big enough to induce a shift to the market-sharing region, then prices and profits decrease (see Table 1, Table 3 and Figure 2). Yet, since the market remains 'covered' in this case, aggregate production remains unaffected.
(iii) When the effect of the stick or carrot is sufficiently severe to induce a shift to the monopolistic pricing region, the market 'uncovers'. This demand decrease results in lower prices, output levels, and profits (see Table 1 and Table 3). ■

**Proof of Proposition 2.** Consumer surplus is computed by using the following formula:

$$CS^s = \int_0^{x_1} U^s(x)\mathrm{d}x + \int_{x_2}^1 U^s(x)\mathrm{d}x.$$

(i) In the competitive pricing region, consumer surplus is harmed by the effect of the *psychic cost*:

$$CS^s - CS = \left(v - a - c - \frac{5}{4}t\right) - \left(v - c - \frac{5}{4}t\right) = -a < 0,$$

In the monopolistic pricing region, there is an additional negative effect of consumers who leave the market:

$$CS^s - CS = \frac{(v-a-c)^2}{4t} - \frac{(v-c)^2}{4t} = -\frac{(2(v-c)-a)\,a}{4t} < 0,$$

because $a < 2(v - c)$. Finally, in the monopolistic market-sharing region, a stick negatively affects the upper bound of the consumer surplus interval, but it does not affect the lower bound:

$$CS \in \left[\frac{1}{4}t, \frac{(v-c)(v-c-2t)}{4t} + \frac{1}{2}t\right] \text{ and } CS^s \in \left[\frac{1}{4}t, \frac{(v-a-c)(v-a-c-2t)}{4t} + \frac{1}{2}t\right].$$

In this case, therefore, consumer surplus either remains constant (when firms set the same price) or it decreases (when firms set different prices).
(ii) In the competitive market-sharing region, a stick induces an increase in the upper bound of the consumer surplus interval:

$$CS \in \left[\frac{1}{4}t, \frac{(v-c)(v-c-3t)}{9t} + \frac{1}{2}t\right] \text{ and } CS^s \in \left[\frac{1}{4}t, \frac{(v-a-c)(v-a-c-3t)}{9t} + \frac{1}{2}t\right].$$

It is straightforward to check that:

$$(v-a-c)(v-a-c-3t) - (v-c)(v-c-3t) > 0 \text{ for } v \in (c + \frac{6}{5}t, c + \frac{3}{2}t]$$

for any $a > 0$ in this pricing region. In this case, therefore, consumer surplus either remains constant (when firms set the same price) or it increases (when firms set different prices). ■

**Proof of Proposition 3.**
(i) Within the competitive pricing region, a carrot policy does not yield any change of consumer surplus since both gross surplus and equilibrium prices are unaffected. Moreover, the market is 'covered' *ex ante* and remains 'covered'*ex post*. (ii) Within the competitive market-sharing pricing region, the effect is as follows. Comparing the new consumer surplus to the benchmark, we obtain that:

$$CS \in \left[\frac{1}{4}t, \frac{(v-c)(v-c-3t)}{9t} + \frac{1}{2}t\right] \text{ and } CS^c \in \left[\frac{1}{4}t + a, \frac{(v-a-c)(v-a-c-3t)}{9t} + \frac{1}{2}t + a\right],$$

so that both the lower bound and the upper bound shift upward. For the lower bound, this can be observed directly. As to the upper bound, note that:

$$CS^c - CS = \frac{(v-a-c)(v-a-c-3t)}{9t} + \frac{1}{2}t + a - \left(\frac{(v-c)(v-c-3t)}{9t} + \frac{1}{2}t\right).$$

Simplifying gives

$$\frac{1}{9t}a\left(a - 2(v-c) + 12t\right) > 0,$$

which holds for $v \in \left(c + \frac{6}{5}t, c + \frac{3}{2}t\right]$. Turning to the monopolistic market-sharing pricing region, note that:

$$CS \in \left[\frac{1}{4}t, \frac{(v-c)(v-c-2t)}{4t} + \frac{1}{2}t\right] \text{ and } CS^c \in \left[\frac{1}{4}t + a, \frac{(v-a-c)(v-a-c-2t)}{4t} + \frac{1}{2}t + a\right],$$

so that both the lower bound and the upper bound shift upward. For the lower bound, this can be observed directly. As to the upper bound, note that:

$$CS^c - CS = \left(\frac{(v-a-c)(v-a-c-2t)}{4t} + a + \frac{1}{2}t\right) - \left(\frac{(v-c)(v-c-2t)}{4t}\right) + \frac{1}{2}t,$$

Simplifying gives

$$\frac{a}{4t}\left(a + 6t - 2\left(v-c\right)\right) > 0,$$

which holds for $v \in \left[c + t, c + \frac{6}{5}t\right]$.
(iii) With monopolistic pricing, we obtain:

$$CS^c - CS = \frac{\left(v-a-c\right)\left(v+3a-c\right)}{4t} - \frac{\left(v-c\right)^2}{4t} = \frac{1}{4t}a\left(2\left(v-c\right) - 3a\right),$$

which is positive for $a \in (v - c - t, 2\left(v-c\right)/3)$ and negative for $a \in \left(2\left(v-c\right)/3, v-c\right)$ within the relevant gross surplus range (*i.e.*, $v \in (c, c+t)$). We conclude that if $a$ is sufficiently small (large), then consumer surplus under monopolistic pricing is higher (lower) than in the benchmark. ■

**Proof of Theorem 1.** This result can be obtained directly by comparing the consumer surplus values in Table 4. ■

**Proof of Proposition 4.**

(i) By Proposition 1, we know that a stick policy does not alter firm profits and outputs in the competitive pricing region. Moreover, the effect of a stick in this region is to lower consumer surplus (Proposition 2). Hence, by the definition of social welfare:

$$W = CS + N + \Pi_1 + \Pi_2 - E, \tag{2.9}$$

and using the fact that $N$ and $E$ remain unchanged in the competitive region, the total effect of a stick on social welfare is negative. Analogously, inside the monopolistic market-sharing pricing region, we know by Corollary 1 that a stick reduces profits and, by Proposition 2, that consumer surplus does not increase. As both $N$ and $E$ are unaffected in this case, social welfare decreases. Finally, in the competitive market-sharing pricing region, we know by Proposition 2 that a stick (weakly) increases consumer surplus and, by Proposition 1, that it leads to a reduction in profits. To see that the latter effect dominates the former, note that by concavity of the social welfare function, social welfare is lowest with maximal price dispersion and highest when prices are equal. Thus, under a stick policy, social welfare ranges within the following interval:

$$SW^s \in [\frac{(v-a-c)\,(12t-(v-a-c))}{9t} - \frac{1}{2}t - e, v - c - \frac{1}{4}t - e - a].$$

It can be easily verified that these values are lower than in the benchmark (*i.e.*, $a = 0$). We conclude that social welfare under competitive and market-sharing pricing is lower than in the benchmark.

(ii) Under monopolistic pricing, both profits and consumer surplus are lower with a stick (Corollary 2 and Proposition 2). Since $N = 0$ in this case, social welfare net of externalities is lower than in the benchmark. This negative impact can only be offset when the reduction in externality costs is sufficiently large. ■

**Proof of Proposition 5.**

(i) By Proposition 1 and Proposition 3, profits and consumer surplus remain unaffected. Moreover, since the market remains 'covered', $N$ and $E$ do not change either. We conclude that social welfare under competitive pricing is the same as in the benchmark.

(ii) Both $N$ and $E$ remain unaffected under competitive market-sharing pricing too. Yet, profits are lower (Corollary 1) and consumer surplus is higher (Proposition 3) than in the benchmark. To see that the first effect (weakly) dominates the second, note that:

$$SW^c \in [\frac{(v-a-c)\,(12t-(v-a-c))}{9t} - \frac{1}{2}t - e + a, v - c - \frac{1}{4}t - e,$$

whereas in the benchmark:

$$SW \in [\frac{(v-c)\,(12t-(v-c))}{9t} - \frac{1}{2}t - e, v - c - \frac{1}{4}t - e].$$

Although it has the same upper bound (obtained at equal prices), the lower bound is strictly smaller for any $a > 0$, since:

$$SW^c - SW = \frac{(v-a-c)\,(12t-(v-a-c))}{9t} - \frac{1}{2}t - e + a - \left(\frac{(v-c)\,(12t-(v-c))}{9t} - \frac{1}{2}t - e\right),$$

which is equal to

$$-\frac{1}{9t}a\left(a-2\left(v-c\right)+3t\right).$$

This term is negative when

$$a-2\left(v-c\right)+3t>0,$$

which holds in the competitive market-sharing pricing region, because $v\in(c+6t/5,c+3t/2]$.
(iii) In the monopolistic market-sharing pricing region, it also holds that $N$ and $E$ remain unaffected by a carrot policy. Yet, in this case the negative profit effect (Corollary 1) is (weakly) dominated by the positive consumer surplus effect (Proposition 3). To see this, note that:

$$SW^{c}\in[\frac{\left(v-a-c\right)\left(6t-\left(v-a-c\right)\right)}{4t}-\frac{1}{2}t-e+a,v-c-\frac{1}{4}t-e],$$

whereas in the benchmark:

$$SW\in[\frac{\left(v-c\right)\left(6t-\left(v-c\right)\right)}{4t}-\frac{1}{2}t-e,v-c-\frac{1}{4}t-e].$$

Although it has the same upper bound (obtained at equal prices), the lower bound is strictly larger for any $a>0$, since:

$$SW^{c}-SW=\frac{\left(v-a-c\right)\left(6t-\left(v-a-c\right)\right)}{4t}-\frac{1}{2}t-e+a-\left(\frac{\left(v-c\right)\left(6t-\left(v-c\right)\right)}{4t}-\frac{1}{2}t-e\right)$$

which is equal to

$$\frac{1}{4t}a\left(2(v-c)-a-2t\right).$$

This term is positive when

$$2(v-c)-a-2t>0,$$

which holds, because $v\in(c+t,c+6t/5]$ and $a\in(v-c-6t/5,v-c-t)$. That is, for any given $v$ in the relevant range, $a$ must be sufficiently small to remain in the monopolistic market-sharing region.
(iv) Finally, in the monopolistic pricing region:

$$SW^{c}-SW=\frac{3(v-a-c)^{2}}{4t}+a-e_{u}^{c}-\left(\frac{3(v-c)^{2}}{4t}-e_{u}\right),$$

which gives

$$\frac{1}{4t}a\left(3a-6\left(v-c\right)+4t\right)-\left(e_{u}^{c}-e_{u}\right).$$

Note that, net of externality savings due to the output reduction, this is positive when

$$\frac{1}{4t}a\left(3a-6\left(v-c\right)+4t\right)>0,$$

which holds for $v\in(c,c+t]$ and $a>\frac{2}{3}t$. If the carrot policy has less impact, then it may still be beneficial for social welfare when the reduction in externality costs is sufficiently large. ■

**Proof of Theorem 2.** This result follows directly by comparing the values in Table 5. ■

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# Chapter 3

# GDP Forecasting: Machine Learning, Linear or Autoregression?

## 3.1 Introduction

The real Gross Domestic Product (GDP) is a single, omni-comprehensive measure of the economic activity that considers the total value of goods and services produced in the economy.[1] It is considered by academics, investors, and regulators as a proxy for the wealth of the economy and an informative indicator that drives the decision-making processes [Provost and Fawcett, 2013]. This makes the forecast of the GDP a relevant issue. Indeed, it is of interest to target national economic policies as well as in other fields, from non-performing loans [Bouheni et al., 2021] to natural disaster [Atsalakis et al., 2020]. When the research question is the forecast of periods of growth or recession a popular methodology is to decompose the GDP in cyclical and trend components relying on appropriate filters. A growth (recession) means that the value of the cycle component is positive (negative) for a given period. However, within this approach, it is only possible to assess the growth (or recession), losing the quantitative information on the prediction. This is instead achieved through the regression methodology. That it is the approach we follow such choice being driven by the limitations encountered in the decomposition of the GDP in cyclical and trend components [Luginbuhl and Koopman, 2004].

The aim of this paper is to show among a set of different models and forecasting strategies which performs better. Classical time series analysis or machine learning? One-step-ahead or multi-step-ahead forecast? Including macroeconomic variables or just the self-explanatory GDP values? How does our model respond to periods of economic turbulence? These are the research questions we aim to provide an answer. Several approaches have been proposed in the literature to forecast the GDP. Indeed, the macroeconomic literature that investigates this topic through the time series approach mainly uses different specifications of VAR [Ang et al., 2006, Brave et al., 2019, Koop et al., 2020], and forecasting improvements can be achieved relying on appropriate Bayesian shrinkage procedures, as highlighted in Bańbura et al. [2010]. Regarding the potential economic indicators that are used as predictors of the GDP, many authors converge on the use of the yield curve that contains information about future economic activity [Giannone et al., 2008, Yiu and

[1]A paper has been published from the extension of the analysis in this chapter. For further information, see Maccarrone et al. [2021].

Chow, 2010]. Estrella and Hardouvelis [1991] find that especially the slope of the yield curve can predict cumulative variations in real GDP for up to 4 years into the future. A similar study is carried out by Bernard and Gerlach [1998] in eight countries finding that, although there are substantial differences across the countries, the slope of the yield provides information about the possibility of future recessions, whereas Ang et al. [2006] find that nominal short rates outperform the slope of the yield curve in forecasting GDP growth. Other studies [Koop, 2013, Schorfheide and Song, 2015] use instead a set of macroeconomic variables to predict the U.S. GDP. Drawing from this strand of literature, e.g. Estrella and Mishkin [1996], Koop [2013], Diebold et al. [2006], we use the yield curve as well as its latent factors and a set of macroeconomic variables, namely Consumer Price Index, Unemployment rate, Federal Fund rates, and Manufacturing Capacity Utilization.
Chauvet and Potter [2013] offer a comparison between reduced form, autoregressive, VAR, and Markow switching models and find that simple time series autoregressive process of order two (AR(2)) outperforms other models in the forecast of the U.S. GDP. Baffigi et al. [2002] provide an example of the use of ARIMA for the U.E. GDP prediction. Lunde and Torkar [2020] exploit more than 120 predictors and then perform a principal component analysis (PCA) to reduce the number of variables. Despite the inclusion of different sources of information in their set-up, the PCA does not provide the economic interpretation of the results.

In this paper, we propose models with macroeconomic variables and other models that take advantage of the self-explanatory information of the GDP relying on both classical time series analysis as well as on a machine learning algorithm. In particular, we forecast the U.S. GDP with SARIMAX and Linear Regression to include additional information such as real and financial measures of economic activity, and use SARIMA as a benchmark for time series analysis. We also exploit the K-Nearest Neighbour (KNN) machine learning methodology. Our goal is to achieve forecasts with high accuracy and a high degree of explainability, which is a best practice for building trust between machine learning and decision-makers, as pointed out in Bellotti et al. [2021]. The idea is that the decision-maker should adopt machine learning as a powerful instrument and should employ it with awareness without regard it as a “black box”.

Many studies explore the potential of machine learning in the field of forecasting. Stone [1977] shows the consistency property of the non-parametric KNN estimator. The model is widely used for classification tasks such as object identification and, due to the easy implementation and explainability, it is also used in applications such as missing data imputation [Bertsimas et al., 2021] and reduction of training set [Wauters and Vanhoucke, 2017] being able to better identify similar objects. The KNN can identify repeated patterns within the time series and, for this reason, is applied to financial time series modeling as in Ban et al. [2013]. Al-Qahtani and Crone [2013] use KNN for forecasting U.K. electricity demand and find that KNN performs better forecasts than other benchmark models. Rodríguez-Vargas [2020] finds that KNN outperforms also two competitors machine learning models, the random forest and the extreme gradient boosting, in terms of accuracy for predicting the inflation. In general, KNN has been referenced as one of the top ten algorithms in data mining [Wu et al., 2008]. Moreover, KNN is especially suitable for cases in which there is not a high number of past observations, i.e., very little past information. As pointed out in Wauters and Vanhoucke [2017], artificial intelligence methods require a minimum number of observations to work properly, whereas, for the KNN, this limitation is not so strict even though a minimum number is required. We employ the KNN model as it offers a simple methodology based on distance metrics to exploit past information.

A compelling way to predict real economic variables is offered by the nowcasting literature, which aims to predict their values in the very short term. When the objective is to study the prediction at horizons lower than a quarter, given quarterly data available for GDP, it is possible to use a consistent two-step estimator, as in Doz et al. [2011], that provides the policymaker with an early estimate of the next quarter including auxiliary exogenous predictors available at a lower frequency. Moreover, this framework can be empowered with alternative variables to boost the economic knowledge. For instance, Spelta and Pagnottoni [2021] use nowcasting to assess the impact of mobility restrictions on the economic activity during the pandemic. In particular, they study the trade-off between economic sacrifices and health outcomes in terms of timely policy suggestions. Foroni et al. [2020] explicitly focus on the forecast and nowcast of the COVID-19 recession and recovery, studying the GDP growth and showing an interesting similarity with the great recession.

We analyze two different forecasting strategies: the one-step-ahead and the multi-step-ahead forecasts [Marcellino et al., 2006, Hu et al., 2020]. The former is more reliable and accurate by construction. However, it results in less information for macroprudential policies. In the multi-step-ahead strategy proposed, we forecast the U.S. GDP up to 12 quarters in advance. This information is potentially extremely valuable although much more challenging.

Finally, we evaluate the performance in terms of mean square error. In particular, we are interested in studying the trade-off between two different aspects: the accuracy of the estimates even when considering a period of economic turbulence, and the forecasting horizon.
The rest of the paper is organized as follows: Section 3.2 introduces the model specifications and the empirical strategy, Section 3.3 illustrates the empirical analysis, Section 3.4 reports the results and Section 3.5 concludes.

## 3.2 Model Specifications and Empirical Strategy

### 3.2.1 Motivations

Closely related to the GDP forecast is the ability to understand whether the forecasted value is associated with growth or recession for the economy. It can be achieved through a classification framework that defines a binary target variable starting from the time series of the GDP. An appealing approach to detect recessions is to decompose the GDP in trend and cyclical components. Among the techniques used, the filters are the most employed in the literature. A well-known technique is the Hodrick and Prescott [1997] filter, also known as the H-P filter, which, through an appropriate parametrized minimization problem, generates the GDP cycle component. Once the cycle component has been detected from the time series, it is then transformed into a binary variable that assumes a value equal to 1 (recession) whenever the cyclical component is lower than zero and 0 (growth) otherwise. Nevertheless, the use of this approach has been criticized. Hamilton [2018] proposes a regression filter as an alternative. Even if such a regression filter overcomes the drawbacks of the H-P filter, it results in some limitations, as discussed in Schüler [2018]. Another procedure as in Bernard and Gerlach [1998] and Estrella and Hardouvelis [1991] is to set the GDP equal to unit during the quarters of recession indicated by the National Bureau of Economic Research (NBER).[2]

[2]NBER considers as recessions two consecutive quarters of negative GDP growth.

Applying the H-P filter to our data, we have encountered the limitations of this filter on the right tail. In Figure (3.1) each line represents a different size of the test set when splitting the entire time series into train and test sets. The red line shows the value of the cycle when the test set contains the 4 quarters of 2020, the green line does the job for 2 years (8 quarters) and so on. The feature that emerges is that the values obtained through the filter are affected by the size of the test set. Assume that the third quarter of 2020 is a recession period. Using the test set with the last 4 and

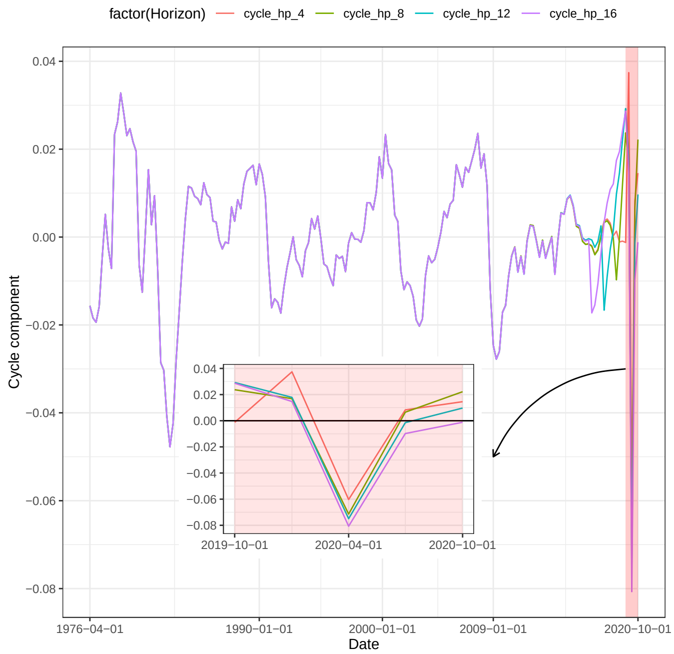


**Figure 3.1:** *GDP cycle, sensitiveness to different horizons until the last quarter of 2020.*

8 quarters, the H-P filter assigns to the third quarter of 2020 a positive value. This means that the classification procedure on the filter generates those quarters as periods of growth (rather than recessions). As a result, the policymaker wastes resources since the model is being fitted on unreliable data. When the test size is long enough, the filter provides the policymaker with appropriate values. Notice that the value obtained comparing the binary outcome derived from the H-P filter and the NBER data, that is, the one for which the two time series match, is 12 quarters in our example. We also control for the Subprime recession. Similarly, more than 4 quarters are required by the H-P filter to match the NBER recession period for the second quarter of 2009, as shown in Figure (3.2). Since H-P filter cannot be considered reliable on the tails, the classification approach does not represent a trustworthy model for predicting growth (recession). Furthermore, another drawback of the classification is the loss of quantitative information: the decision maker is provided with the signal of growth or recession without any kind of information related to the magnitude of the event. We point out that neglecting such quantitative specification comes at a cost as the resulting classification will rely on biased trend-cycle decomposition and, therefore, be misleading. Instead, using predictions based on the actual value of the GDP, the benefit for the policymaker is to capture the intensity of the variation. In this way, the entity of the growth (recession) of the GDP assumes a real value that can be fundamental to address medium-term economic policies. In contrast to the cyclical indicator, this type of information gives the policymaker a wider set of possible actions than

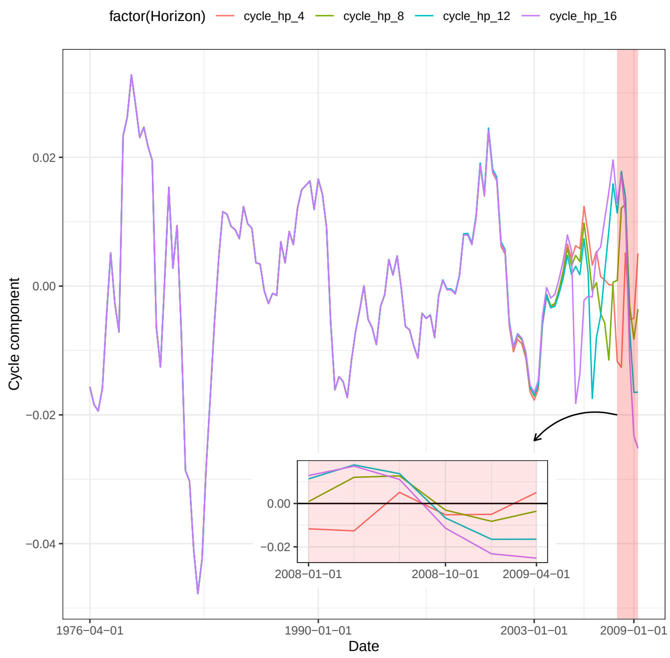


**Figure 3.2:** *GDP cycle, sensitiveness to different horizons until second quarter of 2009.*

a binary pair (growth recession), to better calibrate the reaction to expected changes in the GDP. For instance, the Federal Reserve System (FRS) may be interested in the GDP growth forecast with the aim to set the interest rate against any inflationary threats. On the one hand, when the forecast is based on classification, the only strategy the FRS can apply is to lower or raise the interest rate without knowledge of the value which is needed to set the policy. On the other hand, a quantitative information about the prediction of the GDP growth allows the FRS to optimally set the interest rate, following classical policies such as the Taylor rule [Taylor, 1993] or other rules, to respond to variation of the GDP. For all these reasons, we forecast the GDP with regression techniques.

### 3.2.2 GDP Forecasting Models

We explore different forecasting models to predict the U.S. GDP: KNN, SARIMA, SARIMAX, and a particular specification of the classical linear regression model (LR). Let $t_i$, $i \in \{1, 2, 3, 4\}$ represents the $t_i - th$ quarter of year $T \in \{1976, 1977, \ldots, 2020\}$, so that $t \in \{1, \ldots, 179\}$ is the number of total quarters. Define $Y = \{y_t\}_{t \in R^+}$ the time series of the $log$ GDP. Let $Y^d = \{y_t - y_{t-d}\}_{d,t \in R^+}$ be the $d - th$ order difference between consecutive GDP time series observations. We denote with $\mathbf{X}_n = \{\mathbf{x}_{n,t}\}$ the time series of a generic set of $n$ covariates with $n \in \{1, 2, 3, \ldots, N\}$.

**KNN**. The KNN is a machine learning algorithm useful to solve both classification and regression problems [Wu et al., 2008] based on learning by analogy. We apply the KNN methodology to forecast univariate time series. The rationale behind the use of KNN for time series forecasting is that a time series may contain repetitive patterns. The $i-$th data point (target) can be described by a vector of $n$ covariates $(x_1^i, x_2^i, \ldots, x_N^i)$ that are the lagged values of the target $y_i^1$. Consider a new observation, for example the next quarter $y_{t+1}^1$ to be predicted, whose covariates are known and denoted as $(\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_n)$. Note that there is a relationship between the covariates of the new observations that we want to forecast and the information that we have. The last targets are used as covariates of the new observation. Given that the minimum lag must be at least equal to the number of periods of forecast, in our analysis we use one covariate. For example, if the forecasting period is $h = 10$, the target $y^1_{t+1}$ will be described by the covariate $x_{t-10}$. The KNN algorithm exploits the covariates of the new observation to find the $k$ most similar training covariates according to a specified distance metric. In this study, we use as similarity metric the euclidean distance between the new observation $t+1$ and the $i-$th training observation:

$$\sqrt{\sum_{n=1}^{N}(x^i_n - \bar{x}_n)^2}. \tag{3.1}$$

When predicting a new data point, the algorithm finds the $k$ observed targets with covariates' values (the $x$ lagged quarters) closer to it. Then, it assigns to the new data point the average of the $k$'s target values.

**SARIMA**.The seasonal ARIMA $(p, d, q) \times (P, D, Q)_S$, or SARIMA, is a process that takes simultaneously into account two features of the observed time series: the correlation between consecutive values modelled by standard ARIMA and the correlation between observations that are far from each other that captures the seasonality. Formally, the ARIMA part of the model is defined as:

$$y^d_t = \phi_0 + \textstyle\sum_{i=1}^{p} \phi_i y_{t-i} + b_t - \sum_{j=1}^{q} \theta_j b_{t-j}, \tag{3.2}$$

where $p$ is the autoregressive order of the process with coefficients $\phi_i$ and $q$ is the order of the moving average process with coefficients $\theta_i$. Notice that in a standard ARIMA process $b_t$ is white noise, whereas here it is not due to the existence of unexplained correlation that we model as follows:

$$\begin{gathered} w_t = b_t - b_{t-D}, \\ w_t = \textstyle\sum_{i=1}^{P} \Phi_i w_{t-i\cdot S} + \varepsilon_t - \sum_{j=1}^{Q} \Theta_j \varepsilon_{t-j\cdot S}, \end{gathered} \tag{3.3}$$

where $D$ represents the degree of the integration, $P$ and $Q$ are the seasonal orders of the autoregressive and moving average processes with coefficients $\Phi_i$ and $\Theta_i$, respectively, $S$ is the seasonality, and $\varepsilon_t \sim WN(0, \sigma^2_\varepsilon)$. Using the lag operator $B$ such that $By_t = y_{t-1}$, then (3.2) and (3.3) define the SARIMA $(p, d, q) \times (P, D, Q)_S$ process written in compact form:

$$\phi(B)\Phi(B^S)(1-B)^d(1-B^S)^D y_t = \phi_0 + \theta(B)\Theta(B^S)\varepsilon_t. \tag{3.4}$$

**SARIMAX**. The SARIMAX model is an extension of SARIMA that includes the time series of covariates $\mathbf{x}^{'}_{\mathbf{k,t}}$:

$$\phi(B)\Phi(B^S)(1-B)^d(1-B^S)^D y_t = \beta_n \mathbf{x}^{'}_{\mathbf{n,t}} + \theta(B)\Theta(B^S)\varepsilon_t. \tag{3.5}$$

**Linear Regression** We specify the classical LR model as follows:

$$y^1{}_i = \beta_0 + \beta_n \mathbf{x}_{n,t} + \epsilon_i, \tag{3.6}$$

where the dependent variable $y^1_i$ is the first order differentiated time series at time $t$ and the covariates $\mathbf{x}_{n,t}$ are the variables at time $t$ lagged of $h$ periods where $h$ defines the forecasting horizon. Despite the fact that LR does not account for the autoregressive component, which is typical in a time series, our specification is built in such a way that allows us to include a degree of temporal information.

### 3.2.3 Forecasting Strategies

We propose two different forecasting strategies with the aim of studying the accuracy of the GDP predictions when we include all the available information at present time. We also assess the magnitude of the precision for different forecasting horizons.

#### One-Step-Ahead Forecasting

The one-step-ahead forecasting strategy computes the forecast for one quarter ahead. This implies that the train set, that is the data used for the forecast, is reduced by one observation that corresponds to the forecasting horizon, which is our test set, and covariates have one period lag. We run the prediction of the GDP for each quarter of the period from the first quarter of 2019 to the last of 2020. In each forecast the test set moves back by one quarter and the train becomes one quarter shorter. It is important to highlight that the chosen out-of-sample forecasting horizon includes both one year of normal times (2019) and one year affected by the Sars-Covid-19 pandemic (2020). The forecasting methodology works as follow:

$$\begin{array}{cc} \text{Train Set} & \text{Test Set} \\ y_{1,t_2}, \cdots, y_{T,t_i} & y_{T,t_{i+1}} \\ y_{1,t_2}, \cdots, y_{T,t_{i-1}} & y_{T,t_i} \\ \vdots & \vdots \\ y_{1,t_2}, \cdots, y_{T-h,t_i} & y_{T-h,t_{i+1}} \end{array} \tag{3.7}$$

#### Multi-Step-Ahead Forecasting

In the multi-step-ahead forecasting strategy predictions are run over the horizon that increases at each forecast. In this set up, the end point of the test period is set fixed to the last quarter of 2020 and the starting point moves back by one quarter each forecast. Both GDP and covariates enter the models with a lag equal to the forecasting horizon. The forecasting methodology works as follow:

$$\begin{array}{cc} \text{Train Set} & \text{Test Set} \\ y_{1,t_3}, \cdots, y_{T,t_3} & y_{T,t_4} \\ y_{1,t_4}, \cdots, y_{T,t_2} & y_{T,t_3}, y_{T,t_4} \\ \vdots & \vdots \\ y_{4,t_2}, \cdots, y_{T-3,t_4} & y_{T-2,t_1}, \cdots, y_{T,t_4} \end{array} \tag{3.8}$$

The maximum length of the forecasting horizon here considered is 12 quarters from the first quarter of 2018 to the last of 2020.

## 3.3 Empirical Analysis

### 3.3.1 Data

We measure the economic activity with real U.S. GDP expressed in quarterly frequency and in log scale. The data span the period from the second quarter of 1976 to the fourth quarter of 2020, for an overall of 179 observations, and are available from the database of the Federal Reserve Bank of Saint Louis, Federal Reserve Economic Data, FRED.

*Interest rates and proxies.* Both short-term and long-term U.S. federal government interest rates are used in our study. Short-term interest rates are obtained from Treasury-Bills with maturities 3 and 6 months; long-term interest rates are from the U.S. government bonds with maturities of 2, 3, 5, 7 and 10 years. Drawing on Diebold et al. [2006] and Ang et al. [2006], we exploit an alternative representation of the yield curve through its latent factors, namely the level, slope, and curvature to capture the economic information contained in it. The level is computed taking the average of short-, medium- and long-term bonds; in our study we use the interest rates at 3 months, 2 years and 10 years. The slope is the result of the difference between the shortest- and the longest-term yield, 3 months and 10 years. The curvature is estimated computing the double product of the medium-term yield minus the shortest- and the longest-term yield.

*Macroeconomic variables.* We extend the analysis introducing key observable macroeconomic variables. Following the existing literature [Ang et al., 2006, Diebold et al., 2006, Koop, 2013, Schorfheide and Song, 2015] we select the Consumer Price Index, Manufacturing Capacity Utilization, and Unemployment Rate to illustrate real economic activity whereas the Federal Funds rates proxies the monetary policy. The Manufacturing Capacity Utilization and the Consumer Price Index are differentiated to make the series stationary.

### 3.3.2 Models Fitting

*KNN.* Performing a grid search we find that optimal value of $k$ is 2 for both forecasting strategies.
*SARIMA.* With quarterly GDP data the seasonal period of the series is $s = 4$. Therefore, (3.9) becomes:

$$\Phi_p(B^4)\phi(B)\nabla_4^D\nabla^d y_t = \Theta_Q(B^4)\theta(B)w_t. \tag{3.9}$$

The orders $p, d, q$ and $P, D, Q$ are chosen performing stepwise search to minimize the AIC selection criteria.
*SARIMAX.* By (3.9), (3.5) becomes:

$$\Phi_p(B^4)\phi(B)\nabla_4^D\nabla^d y_t = \beta_n \mathbf{x}_{\mathbf{n,t}}^{'} + \Theta_Q(B^4)\theta(B)w_t. \tag{3.10}$$

*Linear Regression.* We fit a linear regression for each scenario and forecasting strategy. In the one-step-ahead forecasts the covariates have one period lag. In the multi-step-ahead the covariates have a lag equal to the length of the forecasting horizon, which increases at each forecast.

We include a set of covariates $\mathbf{x}_{\mathbf{n,t}}^{'}$ in LR and SARIMAX and study six different scenarios:

Scenario 1 = {Yield Curve};

Scenario 2 = {Yield Curve, Macro-variables};

Scenario 3 = {Macro-variables};

Scenario 4 = {Proxies};

Scenario 5 = {Macro-variables,Proxies};

Scenario 6 (Full) = {Yield Curve, Macro-variables, Proxies},

where the covariates for the yield curve are Treasury-Bills with maturities 3, 6 months and 2, 3, 5, 7 and 10 years. Macro variables are Consumer Price Index, Manufacturing Capacity Utilization, Unemployment rate, and the Federal Funds rate. The proxies are the level, slope and curvature.

## 3.4 Results

### 3.4.1 Model Performances

The KNN model achieves the best forecasting results with respect to SARIMA and specifications that do not include covariates, as reported in Table (3.1). The model selection for each scenario and forecasting strategy is carried out with MSE comparison and also the Model Confidence Set (MCS) procedure [Hansen et al., 2011].[3] Other models that provide good forecasts are models that

***Table 3.1:*** *Average MSE for all periods*

| Strategy | SARIMA | KNN |
|---|---|---|
| One-step | 2,87e-03 | 1,73e-03 |
| Multi-step | 3,84e-03 | 3,02e-03 |

include covariates, namely SARIMAX and LR. We notice that both SARIMAX and LR tend to overestimate the GDP predictions. We also investigate the average of the predictions obtained with the two models (Mean LR-SARIMAX):

$$\hat{y} = \frac{1}{2}(\hat{y}_{t,LR} + \hat{y}_{t,SARIMAX}). \tag{3.11}$$

Table (3.2) reports the average MSE. Among all the models, KNN provides the best forecasts. SARIMAX is able to better predict the GDP one-step-ahead when interest rates (Scenario 1) and proxies (Scenario 4) are considered as covariates. This finding remains true also when forecasting with the multi-step-ahead strategy. Overall, the one step ahead predictions with Scenarios 1 and 4 are the most accurate, whereas the multi-step-ahead forecast with macro variables (Scenario 3) contributes to improve the predictions the most. The Mean LR-SARIMAX performs equally likely as the SARIMAX.

### 3.4.2 Out-of-Sample One-Step-Ahead Forecasting Performance

Table (3.3) displays the prediction accuracy for the forecasting horizon of Scenario 4 (proxies). On the one hand, the KNN provides the best out-of-sample prediction for the second quarter of 2020 that

[3]MCS procedure is undertaken with $\alpha = 0.01$, bootstrap size for computation covariance equal to 3, and block size for bootstrap sampling equal to 10000.

**Table 3.2:** *Comparison of average MSE: one-step- vs. multi-step-ahead.*

| | SARIMAX | LR | Mean LR-SARIMAX |
|---|---|---|---|
| One step | | | |
| Scenario 1 | 2,44e-03 | 1,93e-03 | 2,15e-03 |
| Scenario 2 | 6,19e-03 | 2,41e-03 | 3,96e-03 |
| Scenario 3 | 5,90e-03 | 2,38e-03 | 3,84e-03 |
| Scenario 4 | 2,86e-03 | 1,89e-03 | 2,31e-03 |
| Scenario 5 | 6,10e-03 | 2,43e-03 | 3,96e-03 |
| Scenario 6 | 6,14e-03 | 2,41e-03 | 3,94e-03 |
| Multi step | | | |
| Scenario 1 | 3,66e-03 | 2,50e-03 | 3,01e-03 |
| Scenario 2 | 3,99e-03 | 2,48e-03 | 3,13e-03 |
| Scenario 3 | 4,05e-03 | 2,38e-03 | 3,08e-03 |
| Scenario 4 | 3,97e-03 | 2,40e-03 | 3,06e-03 |
| Scenario 5 | 4,57e-03 | 2,37e-03 | 3,26e-03 |
| Scenario 6 | 3,97e-03 | 2,48e-03 | 3,13e-03 |

**Table 3.3:** *MSE One-step-ahead forecast, Scenario 4*

| Dates | SARIMAX | LR | Mean LR-SARIMAX | SARIMA | KNN |
|---|---|---|---|---|---|
| 2020-10-01 | 2,27e-05 | 3,51e-05 | 2,86e-05 | 1,85e-05 | 2,56e-05 |
| 2020-07-01 | 1,35e-02 | 4,97e-03 | 8,72e-03 | 1,36e-02 | 6,14e-03 |
| 2020-04-01 | 9,03e-03 | 9,79e-03 | 9,41e-03 | 9,05e-03 | 7,33e-03 |
| 2020-01-01 | 2,85e-04 | 3,31e-04 | 3,07e-04 | 3,07e-04 | 2,97e-04 |
| 2019-10-01 | 8,94e-07 | 1,81e-06 | 1,31e-06 | 2,02e-09 | 1,28e-05 |
| 2019-07-01 | 1,03e-06 | 2,84e-06 | 1,82e-06 | 7,14e-07 | 3,07e-07 |
| 2019-04-01 | 1,91e-05 | 3,17e-06 | 9,44e-06 | 1,73e-05 | 4,80e-05 |
| 2019-01-01 | 2,10e-07 | 3,27e-07 | 2,65e-07 | 1,23e-06 | 1,75e-06 |

corresponds to the beginning of the pandemic outbreak. On the other hand, SARIMAX is more accurate in normal periods as it achieves the lowest forecast error for the first quarter of 2019. The second best forecasting model is the LR. Looking at single scenarios that includes the proxies the LR outperforms the other models, confirming the forecasting-power of the yield curve in predicting the GDP.

### 3.4.3 Out-of-Sample Multi-Step-Ahead Forecasting Performance

Table (3.4) shows the results of the second type of forecasting strategy for the Scenario 5 (proxies and macro variables). The best overall performance is achieved by the LR with this specification. We highlight that such set of covariates performs better than other combinations, namely Scenario 1,2,3,4,6. The average MSE with Scenario 5 is the lowest among models with and without covariates. This result holds true for both periods of stability and crisis. A possible justification lies in the fact that the LR does not include the autoregressive term of the GDP that may affect the prediction performance. Indeed, the macro variables may be more reactive improving the prediction compared to autoregressive models.

**Table 3.4:** *MSE multi-step-ahead forecast, Scenario 5.*

| Dates | SARIMAX | LR | Mean LR-SARIMAX | SARIMA | KNN |
|---|---|---|---|---|---|
| 2020q4 | 2,42e-04 | 5,00e-06 | 4,40e-05 | 1,80e-05 | 2,56e-05 |
| 2020q3-2020q4 | 2,68e-02 | 5,64e-03 | 1,42e-02 | 1,74e-02 | 5,08e-03 |
| 2020q2-2020q4 | 3,27e-03 | 3,59e-03 | 3,43e-03 | 3,37e-03 | 3,99e-03 |
| 2020q1-2020q4 | 4,73e-03 | 4,15e-03 | 4,43e-03 | 4,82e-03 | 5,14e-03 |
| 2019q4-2020q4 | 3,77e-03 | 3,48e-03 | 3,62e-03 | 3,89e-03 | 4,19e-03 |
| 2019q3-2020q4 | 2,95e-03 | 2,71e-03 | 2,83e-03 | 3,09e-03 | 4,89e-03 |
| 2019q2-2020q4 | 2,61e-03 | 2,25e-03 | 2,42e-03 | 2,93e-03 | 2,61e-03 |
| 2019q1-2020q4 | 2,26e-03 | 1,73e-03 | 1,98e-03 | 2,23e-03 | 2,56e-03 |
| 2018q4-2020q4 | 2,45e-03 | 1,63e-03 | 2,00e-03 | 2,32e-03 | 1,56e-03 |
| 2018q3-2020q4 | 2,16e-03 | 1,34e-03 | 1,70e-03 | 2,17e-03 | 2,14e-03 |
| 2018q2-2020q4 | 1,94e-03 | 1,14e-03 | 1,48e-03 | 2,12e-03 | 3,06e-03 |
| 2018q1-2020q4 | 1,62e-03 | 7,83e-04 | 1,04e-03 | 1,78e-03 | 1,03e-03 |

## 3.5 Conclusion

This article compares the predictive ability of machine learning, linear, and autoregressive models in forecasting the U.S. GDP. Moreover, we evaluate two different strategies of forecasting, one-step-ahead and multi-step-ahead, considering the self-explanatory power of GDP and the importance of financial and macroeconomic variables as predictors. On the one hand, the machine learning KNN achieves the best performance for the one-step-ahead strategy, providing evidence that in the subsequent horizon, the exploitation of repetitive patterns in the GDP improves the forecast. On the other hand, it loses predictive power when the forecast is performed for a longer horizon. SARIMA performs poorly in the one-step-ahead and multi-step-ahead strategies. Including covariates, SARIMAX obtains a lower error in the one-step-ahead strategy especially with the Treasury-Bills with maturities 3, 6 months and 2, 3, 5, 7 and 10 years (Scenario 1). Considering the multi-step-ahead accuracy, the yield curve has proved to be the best predictor to be paired with this model. Surprisingly, the LR achieves the best performance in the multi-step-ahead forecast using proxies for the yield curve and macro variables (Scenario 5). Moreover, it achieves the second-best performance in the one-step-ahead strategy using only the proxies as predictors and confirming the strong predictive power of the yield curve for the GDP. The results of our analysis suggest the use of the KNN model for one-step-ahead forecasts and that of LR with the use of financial variables for multi-step-ahead forecasts. We propose to overcome the trade-off between accuracy in the estimates and the forecasting horizon, considering the two forecasting strategies which are not mutually exclusive. Indeed, the benefit of a continuous forecasting of both one-step-ahead and multi-step-ahead allows the decision-maker to have two useful instruments: on the one hand the multi-step provides a long-term vision for planning in advance investments, monetary policy, etc., on the other hand the one-step-ahead might tip the scale for possible refinement around the decision taken. There are many possible avenues for future works. A desirable address is to develop a model that includes the international bond yield curve [Byrne et al., 2019], macro variables, and the GDP that takes into account imports and exports of countries the U.S. trade with.

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